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THE LONELINESS DISEASE:
Challenges of First-Generation Chinese-American Parents of Autistic Children

Evaluating Progress of China's New Urbanization Plan

The Declaration Of Female Labor Force Participation In Argentina

Field Theory and Quantum Fluctuations of Fluid Membranes

Congratulations to

Kelsey Wu

for winning

Best Manuscript

Kelsey Wu is a first-year at Harvard College from Cupertino, California planning on concentrating in Government and Statistics. Since 2014, she has been leading Special Melodies, a choir dedicated to young adults with special needs, with the support of Friends of Children with Special Needs (FCSN). For the past two years, she has conducted autism research for the Fung Lab at the Stanford University School of Medicine and served as a contributor to the Stanford Neurodiversity Project. Currently, she works as a research assistant at Harvard Law School, is involved in the Harvard Open Data Project, and sings for the Harvard-Radcliffe Veritones.

December 2019

Dear Harvard Community,

We are delighted to present the Fall 2019 issue of The Harvard Undergraduate Research Journal (THURJ), Harvard's sole peer-reviewed student-run biannual publication dedicated to showcasing outstanding research from the Harvard undergraduate community. For the past ten years, we have been proud to publish high-quality, original research from a wide range of disciplines. In this issue, our authors explore topics as far-ranging as evaluating the progress of China's urbanization plan to studying the quantum fluctuations of fluid membranes. This year's Best Manuscript award goes to Kelsey Wu for her outstanding manuscript that examines the parenting challenges first-generation Chinese-American parents with autistic children go through. We are also excited to present an interview with Professor Shiv Pillai, an esteemed member of the Harvard faculty.

Every year, we work to increase THURJ's visibility in the Harvard community and strengthen our reputation as a professional-quality journal. This year we are proud to have recruited many incoming freshman to our organization and we hope that they are empowered to continue promoting the sharing of scholarly research on campus. In our efforts to promote undergraduate research, THURJ continues to be a leader in the larger national scientific community by working with research journals at our peer institutions and lending our expertise to help students at schools worldwide establish their own undergraduate research journals.

This work would not be possible without the incredible insight, dedication, and support of our faculty advisory board. We would like to thank our student and faculty reviewers, staff writers, and designers for their immense efforts in creating, editing, and polishing this issue. We would also like to extend our unwavering gratitude to our faculty advisor Professor Guido Guidotti for his guidance and wise counsel. Additionally, we are tremendously grateful for continued support from FAS Dean Claudine Gay, FAS Dean of Science Christopher Stubbs, FAS Dean of Social Sciences Lawrence Bobo, Harvard College Dean Rakesh Khurana, Provost Alan Garber, Vice Provost for Research Richard McCullough, HMS Dean George Daley, Harvard Catalyst, the Office of the President, Harvard SEAS and Harvard College.

We are incredibly excited and proud to present our newest issue and to share this outstanding research with the Harvard community. Enjoy!

Sincerely,

Katherine Hung
Co-Editor-in-Chief

Mohamed El-Abtah
Co-Editor-in-Chief

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About Us

The Harvard Undergraduate Research Journal (THURJ) showcases peer-reviewed undergraduate student research from all academic disciplines. As a biannual publication, THURJ familiarizes students with the process of manuscript submission and evaluation. Moreover, it provides a comprehensive forum for discourse on the cutting-edge research that impacts our world today.

At its core, THURJ allows students to gain insight into the peer review process, which is central to modern scientific inquiry. All THURJ manuscripts are rigorously reviewed by the Peer Review Board (consisting of Harvard undergraduates), and the top manuscripts that they select are further reviewed by Harvard graduate students, post-doctoral fellows, and professors. This process not only stimulates faculty-student collaboration and provides students with valuable feedback on their research, but also promotes collaboration between the College and Harvard's many graduate and professional schools. In addition to publishing original student research papers, THURJ is also an important medium for keeping the Harvard community updated on research-related news and developments.

About the Cover

This Cover image shows hands holding up puzzle pieces, in reference to Autism awareness. The puzzle pieces symbolize the complexity of the autism spectrum, each being different colors and sizes to further represent the diversity of people and families who are living with the condition. The diverse problems that individual families go through relates to the topic of the best manuscript "The Loneliness Disease: Challenges of First-Generation Chinese-American Parents of Autistic Children".

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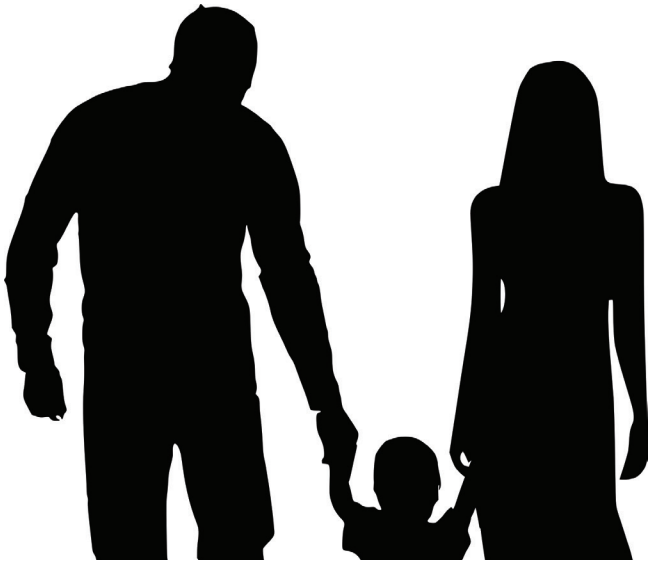

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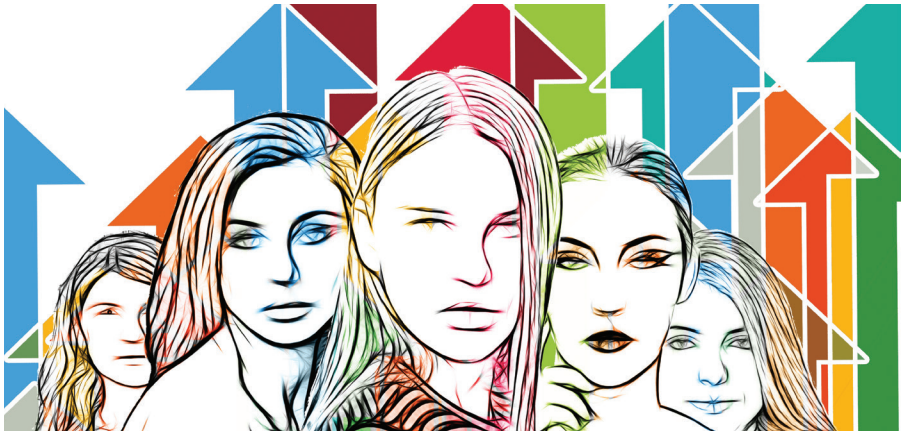
The Loneliness Disease: Challenges of First-Generation Chinese-American Parents of Autistic Children

by Kelsey Wu '23

Autism spectrum disorder (ASD), a developmental disorder characterized by communication deficits, repetitive behaviors, and restricted interests, affects about 1 in 59 children in the United States. While numerous studies examine the experience of parenting an autistic child in the United States, few investigate that of first-generation Chinese-American parents of autistic children. These parents often carry mainland Chinese perceptions of autism, including cultural stigma and social pressure surrounding the disorder. As a result, they face unique challenges while reconciling their Chinese impressions of autism parenting with the unfamiliar American experience. Differences in the age of diagnosis, linguistic terminologies, special education and intervention opportunities between China and the United States, and effective parental social support networks also present additional challenges for first-generation Chinese-American parents. In order to facilitate these parents' navigation of the American service system, American social service providers should cultivate more culturally effective services. This paper examines the challenges that this community faces in the parenting process and proposes a policy—one that utilizes the anonymity of social networks—for American social service providers.



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The Deceleration of Female Labor Force Participation in Argentina

by Anna Giannuzzi '20

Since the collapse of the Argentine economy in 2002 the country has experienced a severe deceleration in female labor force participation. After nearly half a century of sustained growth, improved economic stability and greater social assistance seem to have deterred female entrance to the labor market. While the recent leveling of the female labor force participation rate may suggest a natural rate has been reached, trends identified from the microdata argue this is not the case. Since 2003, there has been an evident shift in the compositional makeup of the female working age population. Therefore, as women become more educated and transition to more formal labor markets the labor force should converge to the participation rates of the middle and high educated population. In addition, cross-section analysis of the wage elasticity of the labor supply of married women since 2003 reveals the growing dominance of the substitution effect over income effect for this group. This attitudinal shift of the married female population could prove critical to the continued growth of a resilient female labor force. However, a decline in real wages as the county has entered a period of rising inflation and economic stability has counteracted female labor force growth.

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Evaluating Progress of China's New Urbanization Plan
by Benjamin Topa '21

This paper contributes to the literature on economic growth in authoritarian contexts by examining, from a political-economic perspective, the Chinese Government's recent efforts at driving growth. I do so by studying the degree to which two cities—Dongguan, Guangdong and Yingkou, Liaoning—have, under the New Urbanization Plan (NUP), used the Hukou system to manufacture economically sustainable urbanization. Ultimately, I conclude that Hukou reforms related to the NUP have been relatively ineffective in directing urbanization, which seems to follow patterns of economic development.

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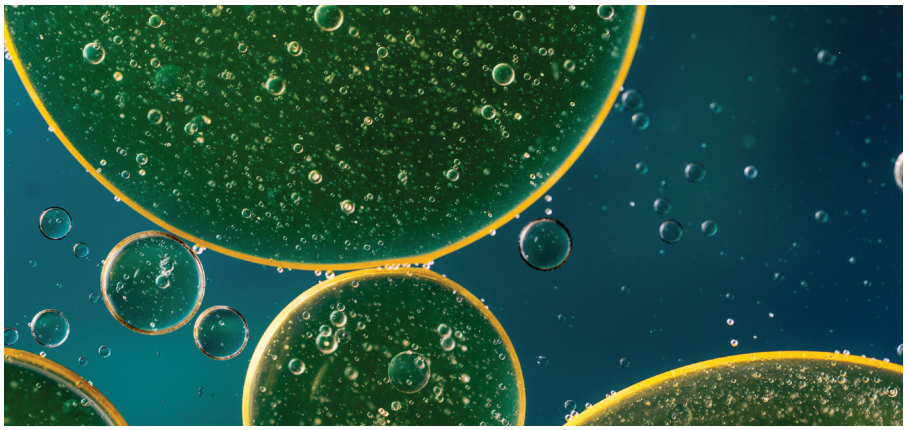
Field Theory and Quantum Fluctuations of Fluid Membranes
by Jimmy Qin '21



Fluid membranes are deformable boundaries between regions, such as the lipid bilayer membranes of biological cells and the nucleation boundaries of condensed regions of superfluid Helium. This paper contains both a review of the physics of fluid membranes and original work on the second-quantization of phonon modes in fluid membranes. The physics of fluid membranes draws heavily from two traditions. The first tradition is fundamental research in biology: why are red blood cells donut-shaped, rather than circular? The second tradition is differential geometry, a branch of mathematics: how can we use the idea of smooth manifolds, which for membranes are two-dimensional surfaces without "kinks," to study the behavior of objects such as red blood cells? My original work in the second half of the paper applies mathematical techniques from bosonic string theory to the study of fluid membranes, which is possible because both membranes and the world-sheet swept out by a string in spacetime -- seemingly unrelated objects -- are two-dimensional surfaces. The goal of my independent research was to study the phonon modes in a fluid membrane. This is useful because it can lower the computational cost of computing certain quantities, such as the free energy and specific heat, and can give us a different and analytically useful way to think about the motion, both equilibrium and out-of-equilibrium, of the small disturbances propagating on a surface.

Research

The Loneliness Disease: Challenges of First-Generation Chinese-American Parents of Autistic Children

Kelsey Wu
Harvard College '23

Autism spectrum disorder (ASD), a developmental disorder characterized by social communication differences, repetitive behaviors, and restricted interests, affects about 1 in 59 children in the United States. While numerous studies examine the experience of parenting an autistic child in the United States, few investigate that of first-generation Chinese-American parents of autistic children. These parents often carry mainland Chinese perceptions of autism, including cultural stigma and social pressure surrounding the disorder. As a result, they face unique challenges while reconciling their Chinese impressions of autism parenting with the unfamiliar American experience. Differences in the age of diagnosis, linguistic terminologies, special education and intervention opportunities between China and the United States, and effective parental social support networks also present additional challenges for first-generation Chinese-American parents. This paper examines the challenges that this community faces in the parenting process and proposes a policy—one that utilizes the anonymity of social networks—for American social service providers. In order to facilitate these parents' navigation of the American service system, American social service providers should cultivate more culturally effective services.

The Loneliness Disease: Challenges of First-Generation Chinese-American Parents of Autistic Children

Autism spectrum disorders (ASD), or autism, affects 1 in 160 children worldwide (World Health Organization, 2017) and about 1 in 59 children in the United States (Centers for Disease Control and Prevention, 2018). Symptoms of autism emerge during early childhood and are most commonly characterized by social communication differences, repetitive behaviors, and restricted interests (American Psychiatric Association, 2013).

Since autism is a life-long neurodevelopmental disorder that hinders social interaction and communication, parents of autistic children often shoulder larger psychosocial burdens than parents of typically developing children. In particular, for parents unfamiliar with the disorder and its implications, an autism diagnosis not only establishes a social divide between themselves and their child, but also evokes many questions about their child's future, engendering emotions of denial, confusion, and frustration. In a study conducted across four Kaiser Permanente Regions serving more than 8 million Health Plan subscribers (KP Northern California, KP Southern California, KP Northwest, and KP Georgia), parents of autistic children felt that their child's problem behavior took a toll on their family and reported concern about their child's future (Becerra, Massolo, Yau, & Owen, 2017). Additionally, after diagnosis, these parents reckon with the difficulty of navigating American service systems, including social service, healthcare, and special education, to find effective interventions for their child.

While numerous studies examine the experience of parenting an autistic child in the United States, few investigate that of first-generation Chinese-American parents of autistic children—for the purposes of this paper, this term refers to parents who emigrate from China to the United States and birth an autistic child in the United States. These parents face unique challenges while reconciling their Chinese perceptions of autism, dubbed as the "loneliness disease" when translated from its Chinese term 孤独症 (gu du zheng), with the unfamiliar and different American experience. Often times, these parents not only lack understanding of the disorder and evidence-based treatments offered by service providers in the United States (Wang, 2016), but also reckon with social pressure and familial isolation due to Chinese cultural beliefs about disability (Wong, 2007). Substantial differences in perceptions of autism and autism parenting between the two cultures hinder Chinese-American parents from gaining access to and taking advantage of the American services system.

American social support programs for parents of autistic children—which typically target parents with American perceptions of autism—often do not provide effective support for Chinese-American populations due to the cultural discrepancies between Caucasian-American and Chinese-American parents (Wang, 2016). The unique needs of first-generation Chinese-American parents, therefore, often remain unaddressed, leading to elevated levels of parental stress in these Chinese-American parents (Wang, 2016). For first-generation Chinese-American parents of autistic children, access to culturally effective education and training from American service providers might facilitate adjustment to the unfamiliar experience of parenting an autistic child in the United States.

This paper aims to cover the unique experiences of these parents and proposes potential methods of culturally effective support for Chinese-American parents from American service providers. While this culture-specific support could apply towards many aspects of the American services system, this paper specifically targets social service providers.

Challenges of Autism Parenting in China

First, we must briefly summarize aspects of the parenting experience of parents of autistic children in China, as this impression establishes expectations for first-generation Chinese-American families regarding how the same process may unfold in the United States.

While autism was first diagnosed at Johns Hopkins Division of Child and Adolescent Psychiatry by Austrian-American psychiatrist Leo Kanner in 1943 (Cohmer, 2014), the disorder has a relatively brief history in China. Dr. Tao Kuo-Tai issued the first-ever

diagnosis of autism in China in 1982 at Nanjing Brain Hospital, nearly four decades after Kanner did (Huang, Jia, & Wheeler, 2013). Although Dr. Kuo-Tai published a report that same year detailing the four cases of autism he had encountered, his findings did not have an immediate or profound effect on public awareness of the disorder or autism diagnostic procedures in China. Even today, most Chinese people remain unaware of the term "autism" and lack information about the disorder (Huang, Jia, & Wheeler, 2013). The Chinese government's refusal to publish statistics on autism diagnoses in China perpetuates this deficiency of reliable information amongst the Chinese people (Huang, Jia, & Wheeler, 2013). As a consequence, many uninformed and inexperienced parents, desperate to discover a "cure" for their children, establish their own autism intervention programs, often providing services that are not necessarily evidence-based (Huang, Jia, & Wheeler, 2013). In China, therefore, information and services for families with autistic children remain deficient, due to unreliability in data collection, an absence of government-funded services, a lack of awareness in the general public, and mainland Chinese stigmas regarding disabilities.

Varying Prevalence Estimates

Regarding the prevalence of autism in China, a single reliable estimate does not seem to exist, as statistics vary significantly across several sources. For one, the Chinese Central Government has never conducted nation-wide epidemiological studies on the prevalence of autism and, consequently, has also never released official statistics on the number of autism diagnoses (Huang, Jia, & Wheeler, 2013). In a study conducted by Medical University in Shandong Province, Wan et al. (2011) analyzed 18 community-based screening studies from mainland China with a range in rates from 2.8 to 30.4 per 10,000. The pooled prevalence of 5 of these studies produced even more variant results, with a range in rates from 7.3 to 75.3 per 10,000. These sizable differences largely result from methodological discrepancies, such as source population and diagnostic criteria, amongst investigated studies. While there exists a tremendous variance across data, there appears to be an overall increased prevalence over time, one "that is more than a simple increase in clinical awareness or an increase in care-seeking" (Wan et al., 2011). If this upward trend holds true, lower prevalence in certain regions may result from uneven progress in the autism diagnosis across various regions, revealing a lack of uniformity in autism research, awareness, and diagnostic criteria. They demonstrate the need for not only more standardized diagnostic methods, but also a more consistent dispersal of information about the disorder across China, namely through doctors, teachers, and social workers knowledgeable about autism intervention.

Lack of Government-Funded Support

Apart from a deficiency of reliable information about autism diagnosis and prevalence, another obstacle to obtaining effective autism treatment in China derives from a lack of government-funded support for autistic children. While the concept of special education was first introduced by Western missionaries as early as the late nineteenth century, real development of China's special education provisions did not occur until the 1980s, with the passage of the 1986 Compulsory Education Law (Huang et al., 2012) and the establishment of the China Disabled Persons' Federation (CDPF) in 1988 (Richardson, Sheppard, & Barriga, 2013). Monitored by China's State Council, the CDPF officially seeks to "represent, serve, and manage" people with disabilities and conducts a "nationwide network 'reaching every part of China' and 80,000 full-time workers" (Richardson, Sheppard, & Barriga, 2013). While the CDPF's goals may seem laudable on paper, its implementation lacks regulation, follow-through, and consistency. For example, while the CDPF promises distribution of governmental stipends to the disabled, only those with significant levels of disability qualify (Mooney, 2012). These stipends also vary by region, running from as little as 100 yuan (USD $15) to 600 yuan (USD $88) (Mooney, 2012).

Although special education programs have grown rapidly over the past twenty years, most autistic children are excluded from schools, resulting in isolation from public life (Huang et al., 2012). Before 2006, Chinese Disability Law did not cover autism as a disability, which resulted in the inability of many autistic children to enter government-run public schools, even if the schools provided special education (McCabe, 2012). On the rare occasion that a special education school accepts a child with autism, these children eventually face probable rejection or expulsion. In response to questioning from parents of children with disabilities, schools in China often justify their exclusion of autistic children with a variety of reasons, including a deficiency of resources and trained instructors, reluctance to adjust to additional responsibilities, or the potentially negative impacts of disabled children on the learning environments of typically developing children (Richardson, Sheppard, & Barriga, 2013). A Human Rights Watch study received a number of reports from parents of children with intellectual disabilities or autism about intentional negligence from teachers due to sub-par performance (Richardson, Sheppard, & Barriga, 2013). Consequently, many autistic Chinese children—a number which is difficult to scale quantitatively due to lack of any nation-wide epidemiological study—remain unable to receive any formal schooling, which causes families to turn to private agencies and non-governmental organizations for education and intervention.

Eclectic Intervention Programs

Due to the scarcity of available government-funded services, many families with autistic children have sought help from non-governmental, private organizations for intervention and treatment. While some programs utilize evidence-based methods such as Applied Behavior Analysis (ABA) and University of North Carolina's Treatment and Education of Autistic and Related Communication Handicapped Children (TEACCH), most intervention programs—many of which are founded by untrained parents of autistic children—involve a mix of various methods, in hopes that a combination of methods will maximize effectiveness (McCabe, 2013). Amongst many of these private organizations, quantity and speed seem to trump quality, resulting in the non-evidence-based, simultaneous utilization of multiple methods by many organizations (McCabe, 2013). Additionally, parents, often lacking knowledge about autism intervention, determine a program's effectiveness based on the sheer quantity of different services provided. This mindset encourages many intervention programs to offer instruction through multiple methods or demonstrate the utilization of all the latest "equipment" for autism intervention, with little explanation as to how the combination of methods was determined (McCabe, 2013). This quantitative abundance of interventions, also called eclectic intervention, involves multiple transitions between activities throughout the day (McCabe, 2013).

Because these private organizations rely heavily upon tuition

and fees for funding, they often prioritize the parental satisfaction over quality of intervention methods, in order to sustain their sources of income. To Chinese parents of autistic children who lack understanding of the disorder and desire rapid improvement, the utilization of numerous, simultaneous interventions understandably holds appeal. As a result, many private intervention programs advertise and provide a myriad of available methodologies, tending to rotate amongst different methods in a cursory manner and pursue the latest intervention method rather than the most effective one (McCabe, 2003). While autism professionals themselves resist adopting eclectic or "fad" interventions, parents often pressure programs to provide such measures, insisting that a "comprehensive program" must be the most effective (McCabe, 2003). Consequently, while the number of autism intervention programs in China may be increasing, the effectiveness of such programs is questionable, due to monetary incentives and pressure from uninformed parents.

Various academic studies have also demonstrated the ineffectiveness of employing several autism intervention methodologies simultaneously, in comparison to delving rigorously and consistently into a single type of intervention. In a 2003 comparative study investigating the effectiveness of intensive and eclectic interventions, Howard et al. investigated the effects of intensive behavior analytic treatment (IBT) and eclectic treatments for preschool-aged children diagnosed with autism. Two groups of study participants received different types of intervention treatment. Children in the IBT group received 25 to 30 hours per week of one-on-one intervention, which utilized only applied behavioral analysis conducted by instructional assistants. These children also received individualized evaluations based upon personal objectives for improvement. Children in the eclectic treatment group, on the other hand, received treatment utilizing a variety of intervention methods, including sensory integration therapy and TEACCH model activities. After each group of children had undergone approximately 14 months of treatment, Howard et al.'s study evaluated the two groups again and found substantially higher learning rates for autistic children undergoing intensive intervention. The findings of this study align with previous statements of the Institute of Medicine's National Research Council, which recommend autistic children receive intensive and systematically planned intervention (Blenner, Reddy, & Augustyn, 2011). Because children with autism "often do not respond well to changes in routines [and] have substantial attentional difficulties" (Howard, Sparkman, Cohen, Green, & Stanislaw, 2005), eclectic programming often proves less effective than intensive intervention that is more planned and less variable.

Stigma and Cultural Implications

Chinese cultural stigma about disabilities, which originates from cultural values that differ significantly from those of the United States, presents another challenge to mainland Chinese parents of autistic children. A comparative study conducted by Fong et al. in 2002 found that mainland Chinese attitudes towards epilepsy and other disabilities were significantly more negative than those in other countries or regions, including Hong Kong and western countries (Fong et al., 2002). As explained by Fong et al., this generally more negative perception of disabilities by mainland Chinese people grounds itself in differences between Western and Eastern cultures.

While stigma towards autism and other neurodevelopmental disorders exists in both Western and Eastern cultures, traditional Chinese beliefs about "face" and disability present additional stress to Chinese parents of autistic children. Tracing to Confucianist constructs, several Chinese core values reveal the perceived influence of disability on family reputation and societal harmony. One such belief states that disability and other fates considered unfavorable by society indicates moral regression or failure to complete social responsibilities by individuals in the family (Chiu et al., 2013). Chinese people, therefore, tend to perceive disability as the result of parental sin committed in this lifetime or a previous lifetime (Liu, 2001). Additionally, because Chinese cultural values emphasize filial pride and repute, stigma about disabilities reflects almost immediately upon one's own family, often resulting in intentional distancing by other relatives from parents of autistic children in order to protect and maintain the reputation of the remaining network (Yang & Kleinman, 2008). The concept of "face" (*mianzi*), which represents social prestige derived from successful completion of well-recognized societal responsibilities (Hwang, 1987), and the expectation to preserve it seems omnipresent in highly collectivist Chinese societies, not only on individual levels but also on the family or community scale. Chiu et al. expressed the concept of *mianzi* as "honour one, honour all; disgrace one, disgrace all" (Chiu, Wong, & Yang, 2003, p. 1119). As a result of this familial extension of one's reputation, distant relatives experience additional embarrassment, shock, and shame when a child in the family is diagnosed with autism, precipitating the subconscious or conscious detachment by extended family members from immediate relatives of the autistic child. Chinese parents of autistic children often report experiencing "self-blame or blame by others" as well as "disgrace and criticism from the community" (Chen, 2014, p. 3). In an interview-based 2009 study, Professor Helen McCabe, a specialist in the experience of autism in China, interviewed 66 families with autistic children in China and found that the three most recurring parental responses to learning of ASD diagnosis were shock, devastation, and lack of understanding (McCabe, 2009). While these reactions may not be unique to Chinese parents, parents reported that the shock of the diagnosis intensified as a result of isolation and lack of support from throughout the parenting process (McCabe, 2009).

In particular, China's one-child policy, established in 1979 in order to control the country's rapid population growth (Dewey, 2004), limited married couples to only one child. Presented with a singular opportunity to parent a child and advance the family lineage and repute, Chinese parents hold high expectations for the family's first and only child, even before birth. As a result, a diagnosis of autism is all the more devastating for hopeful parents. Confused and uncertain about their child's future, these parents reckon with not only personal sentiments of embarrassment, shock, and shame, but also ostracization from relatives, friends, and other significant support systems, further contributing to parental stress (McCabe, 2009). Hence, in China, the name "loneliness disease" holds a double meaning—it serves applicable to both the condition itself as well as the parents of the autistic individual. The symptoms of the condition itself impair an individuals' social skills, while the diagnosis of the condition serves to isolate the parents of the autistic individual from various social groups.

Challenges of First-Generation Chinese-American Parents of Autistic Children

Various discrepancies between American and Chinese social service provision and cultural perception of autism act as another challenge for first-generation Chinese-American parents of autistic children. This section seeks to delineate these potential challenges and identify their causes.

Age of Autism Diagnosis

Age at which autism is diagnosed acts as one key difference between American and Chinese experiences of parenting an autistic child. Quantitatively, the difference between the average age of diagnosis in the United States and China appears minor—the mean age of diagnosis of ASD in the United States is 3 years and 10 months (Centers for Disease Control and Prevention Department of Health and Human Services [CDC-HHS], 2007), while a study conducted by Nankai University researchers discovered that most diagnoses of ASD in China occur at 3 years and 4 months in China (Wang, Wang, Guo, & van Wijingaarden, 2018). While this 6-month gap in mean age of diagnosis between the two countries does not appear significant, measures taken to promote early autism diagnosis have differed greatly in the United States and China.

In recent years, the United States has issued significant governmental efforts pushing for early autism diagnosis and intervention, which is crucial for social development of autistic children. Based upon recommendations by the American Association of Pediatrics (AAP), American pediatricians currently conduct autism diagnostic assessments for every child at 18- and 24-month well-child checkups, even if the child does not exhibit symptoms (Division of Birth Defects, National Center on Birth Defects and Developmental Disabilities, & Centers for Disease Control and Prevention, 2018). This policy suggestion has proven effective in early diagnosis of the disorder. According to a 2013 study conducted by the Center for Autism Research at the Children's Hospital of Philadelphia, children who attended well-child checkups per the AAP guidelines received diagnoses 1.6 months earlier than children who received no well-child care (Daniels & Mandell, 2013).

On the other hand, while the Chinese government has made some strides towards promoting early autism diagnosis, implementation has been largely deficient due to unclear policy definitions by the Chinese government. While China's Outline of the Work for Persons with Disabilities aimed to promote early autism screening and support special education schools, its policy suggestions for private organizations lack detail, which complicates implementation (Zheng, Maude, & Brotherson, 2015). China's screening systems also do not include a standardized diagnostic instrument for autism, resulting in unreliable diagnoses (Zheng, Maude, & Brotherson, 2015). Additionally, the country is deficient of pediatricians able to diagnose autism. While 1.46 pediatricians serve every 1000 children in the United States, the ratio of pediatrician to children is 0.26 per 1000 children in China (Li, Chen, Song, Du, & Zheng, 2011).

Following a potentially doubtful diagnosis, the child is required to register for an identification card, which supposedly permits disabled children to enroll in government-funded Early Childhood Intervention programs (Zheng, Maude, & Brotherson, 2015). The central government has largely neglected these programs, however, leaving local governments to regulate and monitor the quality of these programs (Zheng, Maude, & Brotherson, 2015). Consequently, the quality of these programs varied drastically across regions. The most effective ones, therefore, are highly selective and typically concentrate in urban regions with high cost of living (Zheng, Maude, & Brotherson, 2015). Due to the convoluted and inefficient steps that follow an autism diagnosis, Chinese parents of autistic children are understandably reluctant to seek out diagnosis after observing irregular behaviors. The lower rate of diagnosis in China in comparison to that in America, therefore, stems from deficiency in diagnostic assessment, ineffective implementation of policy, and disinclination by parents to seek early screening for their children.

As a result of differences in the age of autism diagnosis, quality of diagnostic assessment, and motivation behind seeking diagnosis, the attitudes and perceptions about early autism diagnosis held by Chinese and American parents hold stark contrasts. It stands to reason then, that children of first-generation Chinese-American parents—parents who maintain a Chinese understanding of the autism diagnostic and intervention process—have been diagnosed later than their American counterparts (Tuzon, Verma, Wu, & Yoon-Hendricks, 2017). Philadelphia-based clinical social worker Karen Krivit, who helps oversee the 8,000 special needs children in the city's system, cite Asian immigrant children as the largest group of children receiving late diagnoses, claiming that these children "could've been getting services at age two getting first diagnosed at age five or six" (Tuzon, Verma, Wu, & Yoon-Hendricks, 2017). As early diagnosis and intervention are particularly important for autistic children, this delayed age of diagnosis, deriving from a lack of parental knowledge about American diagnostic processes and intervention programs, demonstrates a dire need for more accessible resources for first-generation Chinese-American parents.

Cultural Beliefs

While stigma surrounding disabilities exists in both American and Chinese culture, certain unique aspects of Chinese beliefs—association of autism with past sin and the familial extension of shame—present an additional obstacle for the transition process of first-generation Chinese-American parents of autistic children. While the immigrant parents themselves usually accept Western notions of causality such as genetics and evidence-based intervention (Chen, 2014), their family members, who mostly carry Chinese perceptions of the disorder, typically perceive disability as a "punishment for the disabled person's sins in a past life or the sins of the person's parents" (Liu, 2005, p. 68). As a consequence, Chinese relatives of these emigrated parents tend to neglect and isolate the immediate family members of the autistic child in order to maintain family pride or save *mianzi*, similar to the existent situation within China. In an interview study conducted by Brandeis University researcher Jin Yun Chen in 2014, first-generation Chinese-American parents of autistic children expressed limited support from families due to stigma or lack of understanding (Chen, 2014).

Cultural scorn surrounding a diagnosis of autism in the family, therefore, often results in a desire to hide the disorder, leading to delays in diagnosis amongst Chinese-American families. Barbara Wheeler, associate professor for the University of Southern California's University Centers for Excellence in Developmental Disabilities who focuses on racial disparities across various service systems, stated that "Asians in particular have a problem speaking up for additional services for family members with disabilities compared to whites" (Tuzon, Verma, Wu, & Yoon-Hendricks, 2017). When Californian teenager Kevin Chang was first diagnosed with

autism at the age of 15, his grandmother blamed herself (Tuzon, Verma, Wu, & Yoon-Hendricks, 2017), citing Kevin's speech delay as a result of her inability to speak English. Kevin's situation is not unique—many Asian, specifically Chinese, immigrant families who birth autistic children blame themselves for the presence of the disorder in the family. Coupled with internal shock and embarrassment that accompanies the diagnosis (Tuzon, Verma, Wu, & Yoon-Hendricks, 2017) the stress of parenting an autistic child in a cultural environment that perceives the disorder as a product of sin becomes increasingly burdensome. This perceived sense of familial shame often results in a hesitance to officially label the child's irregular behaviors and desire to conceal the child from the public sphere. Consequently, Chinese-American families largely fail to seek out early diagnosis and intervention (Tuzon, Verma, Wu, & Yoon-Hendricks, 2017), both of which play crucial roles in social development processes of autistic children.

Language Barriers

Another challenge that Chinese-American parents of autistic children face while navigating the American services system is the language barrier. While linguistic obstacles may seem evident, the lack of Chinese translations of commonly used technical terms in the autism field hinder communication between social service providers and Chinese-American parents. One such example is the English term "gross-motor planning." While the term is typically used to describe large-scale repetitive movements that autistic children exhibit, "gross motor planning" does not translate directly to any term in the Chinese language (Tuzon, Verma, Wu, & Yoon-Hendricks, 2017). Discrepancies in definition, therefore, pose opportunities for misinformation between parents and American service providers, establishing yet another barrier to understanding autism for these parents.

In addition, many American agencies do not provide interpreters during appointments, therapy, or in-home visitations due to the lack of Asian and Pacific Islander (API) autism professionals, according to San Francisco-based speech therapist Dr. Betty Yu (Tuzon, Verma, Wu, & Yoon-Hendricks, 2017). In an interview with reporter Melody Cao, Dr. Roger Jou from Yale Medical School's Child Study Center commented that these language barriers also pose a significant obstacle in communicating updated, reliable research about the disorder to Chinese-American parents. He mentioned that many of these Chinese-American parents, especially those who are in a desperate search for effective interventions, adopt interventions through word of mouth from other parents, instead of through consultations with professionals or doctors (SinoVision & Cao, 2016). This informal dissemination of knowledge fosters mistreatments, since autism displays a vast spectrum of symptoms. Interventions that demonstrate effectiveness for one child often do not produce the same results for another.

Consequently, first-generation Chinese-American parents not only lack an understanding of social service opportunities due to the discrepancy between the quantity and quality of services offered in the United States and China, but also struggle with navigating American social service systems due to misinterpretation within translation. For these parents to fully and more effectively take advantage of American social service systems, there is a dire need for not only more resources in the Chinese language, but also Asian and Pacific Islander autism professionals.

Differences in Effective Social Support

Facing challenges due to linguistic and cultural divides, first-generation Chinese-American parents also struggle to locate culturally effective psychological counseling. American parental counseling, primarily catered towards European Americans, includes services that provide explicit social support, which is defined as "the advice, instrumental aid, or emotional comfort one can recruit from social networks" (Taylor, Welch, Kim, & Sherman, 2007, p. 832). These services include support groups, open discussion, and other methods that involve "active disclosure and explicit transactions of support seeking" (Taylor, Welch, Kim, & Sherman, 2007, p. 831). The sharing of personal stories and experiences, a key component in explicit social support systems, typically serve European Americans well, due to the highly individualistic and self-defining aspects of Western culture (Taylor, Welch, Kim, & Sherman, 2007). European Americans tend to maintain relationships with others with the assumption that few obligations exist (Miller, Bersoff, & Harwood, 1990).

Asian Americans, on the other hand, tend to perceive their communities as interdependent groups and follow a more collectivistic point of view (Markus & Kitayama, 1991), which is especially prevalent in Chinese culture. When the individual is understood as an entity connected to the rest of the community, the needs of the individual hold less significance than and become secondary to the collective goals of the group (Kim & Markus, 1999). In order to place the needs of the social group first, therefore, individuals are expected to withhold the disclosure of personal problems and focus their energies on the greater good, with the purpose of preserving communal harmony (Kim & Markus, 1999). Because of this cultural discrepancy, therapeutic support groups that work for European Americans tend not to work as effectively for Asian Americans.

In a 2007 study investigating the effectiveness of different types of social support on European Americans and Asian Americans, Taylor et al. measured stress levels of the two demographics with two different types of social support: explicit social support, which involved the explicit sharing of personal struggles, and implicit social support, which was defined as "the emotional comfort one can obtain from social networks without disclosing or discussing one's problems vis-a-vis specific stressful events" (Taylor, Welch, Kim, & Sherman, 2007, p. 832). In contrast to explicit social support, implicit social support often serves to remind individuals of the existence of others in similar situations, rather than explicitly discussing personal issues (Taylor, Welch, Kim, & Sherman, 2007). Taylor et al.'s study (2007) found that explicit social support alleviated psychological distress for European Americans, but actually intensified that stress in Asian Americans. Implicit social support, on the other hand, worked effectively for Asian Americans and adversely for European Americans. Overall, Asian Americans seem to perceive sharing personal problems as a burden on the community, and experience increased stress in the face of negative cultural implications that come with burdening the community with personal problems. Rather, they find more comfort in the existence of silent solidarity, without the disturbance of any communal harmony.

In the context of the autism community, many American support groups involve the sharing of personal struggles. As the population of Chinese immigrants is increasing around the country, support groups established by social service providers also have an increased likelihood of encountering Chinese-American parents of children

with autism. Most social service organizations, however, provide explicit social support, which may fail to relieve or even worsen the stress of Chinese-American parents. The deficiency of culturally appropriate support groups for Chinese-American parents engenders more distress in the already highly stressful parenting process of an autistic child. In order to provide properly for first-generation Chinese-American parents, social service organizations should consider employing implicit rather than explicit support when establishing support groups and other social support programs.

Policy Proposal

In light of the obstacles that first-generation Chinese-American parents of autistic children face, American social service providers for families with autistic children, particularly those located in regions with significant Chinese-American presence, should utilize more culturally sensitive services. In particular, this policy proposal suggests the formal integration of social networking into the programming of American social service providers. Through the usage of anonymous social networking, social service providers may be more equipped to interact with Chinese-American parents of autistic children, ultimately facilitating the transition towards more meaningful, face-to-face intervention with pediatricians, child development specialists, social workers, and other parents of autistic children. Specifically, this policy proposal consists of the following steps:

1. Formal integration of anonymous social networking into the programming of social service providers
2. Informational seminars, distributed via social networking, to encourage parents to attend well-child checkups and adopt a strength-based perception of autism
3. Referral to face-to-face intervention with local autism professionals and community providers

Although social network based initiatives have already taken effect in communities of families with autistic children, most social service organizations have yet to formally integrate social networking into their service provisions, which Chinese-American parents, in particular, would benefit from. The Charles B. Wang Community Health Center, a non-profit organization centered around providing more accessible and culturally effective health care to New York City's Asian-Americans, is one organization that has adopted social networking as a form of outreach. The Health Center's Child Development and Special Needs team established an official WeChat group, designed to provide a platform for support and discussion amongst Chinese-American parents of autistic children. The team saw positive results, discovering that parents of autistic children were "more willing to share online anonymously" (Cao, 2016). While the notion of increased personal sharing under the realm of anonymity appears intuitive, the concealment of identity serves particularly well for Chinese-American parents. Carrying mainland Chinese cultural perceptions of the disorder, these Chinese-American parents often lack familial support throughout the parenting process and desire to hide their child's diagnosis. Parents, therefore, feel significantly more comfortable sharing personal stories and struggles through anonymous means. By simply adding parents into nameless social networking forums, Chinese-American parents would be receiving implicit social support, which was found to be more effective in alleviating psychological stress for Asian Americans than explicit social support (Taylor, Welch, Kim, & Sherman, 2007). For Chinese-American parents, utilizing social networking forums—ones that allow users to comment and discuss at their own convenience and volition—instead of face-to-face parental support groups would more effectively provide psychological comfort, as many Chinese-American parents do not find relief in sharing personal stories with others (Taylor, Welch, Kim, & Sherman, 2007). Rather, these forums would offer social support in the form of knowledge that other parents also tackle similar issues and problems, which is a form of implicit social support, as defined by Taylor, Welch, Kim, and Sherman. These forums would also offer an easily accessible channel for exchange of advice amongst parents, if they choose to do so.

With the implementation of this policy, social service organizations will be encouraged to establish a presence on social media platforms—WeChat, in particular—for their respective special needs communities. WeChat, a Chinese social media app with more than a billion monthly users (Kharpal, 2019), most likely provides the most direct channel of communication to first-generation Chinese-American parents, especially in Chinese-American heavy regions. These community groups, in turn, will provide seminars held by API trained autism professionals, who are trained and well-versed in Chinese cultural differences and can most effectively facilitate the transition process. Through electronic dispersion of information about American social service systems, these WeChat groups will provide an anonymous, and therefore more discreet, avenue of informational support for parents who hesitate to disclose their child's diagnosis in support groups. The dispersal of information via social media, however, is merely a means to achieve the goal. The program ultimately aims to bridge the gap between Chinese-American families and real clinicians by encouraging Chinese-American families to seek out professional face-to-face help. To effectively prepare clinicians—particularly ones serving regions with dense Chinese-American populations—for these in-person meetings, American social service organizations should provide formal cultural training programs for autism professionals, including special education teachers, pediatricians, school-based psychologists, and speech pathologists. These training programs would offer clinicians historical, social, and political context of the perspectives on autism held by Chinese-American parents, thereby facilitating conversations around the process of obtaining information about the American social service system, including the acquisition of an Individualized Educational Plan, as well as transitioning to a new cultural norm.

Informational seminars will also emphasize the significance of autism advocacy—on the part of the parents—in the parenting process. Because Chinese-American parents, in particular, often desire to hide their children's irregular behaviors from the public sphere, an emphasis on an advocacy-based mindset rather than one that invites shame and embarrassment would potentially alleviate the stress of the transition between Chinese and American experiences of parenting autism. One pertinent ideological movement that has emerged from the autistic community is neurodiversity, a concept that "neurological differences like autism and ADHD are the result of normal, natural variation in the human genome" (Austin & Pisano, 2017). In other words, neurodiversity aims to influence society to perceive children with autism as representing a different but valuable approach to problem-solving. The notion of neurodiversity is closely tied to strength-based approaches,

as opposed to deficit-based approaches, to autism intervention. According to an infographic designed by Harriet Cannon, Disability Advisory Team Manager at the University of Leeds, some common strengths of autism include attention to detail, deep focus, strong observational skills, absorption and retention of facts, and novel approaches to problem-solving (Cannon, 2018). In recent years, an increasing number of corporations, including Microsoft and SAP, have begun to recognize the strengths of autistic individuals in the workplace, implementing measures that promote the hiring of neurodiverse individuals (Austin & Pisano, 2017). While these recruitment programs are relatively young, they have not only yielded increased levels of workplace productivity and innovation, but have also encouraged a broader definition of neurodiversity—one that also encompasses strength-based evaluations of those who are not on the spectrum (Austin & Pisano, 2017).

Parental adoption of a strength-based mindset such as one demonstrated by these corporations and in the tenets of neurodiversity, therefore, would potentially impart more hope in these Chinese-American parents for their children's futures. Because first-generation Chinese-American parents derive their perceptions of autism from a culture that encourages concealment of the diagnosis, this notion of building upon strengths in an autistic individual may serve to promote autism advocacy amongst Chinese-American parents. The interspersion of these ideas about strength-based perceptions of autism via WeChat seminars, during which parents of autistic adults and directors of neurodiverse vocational programs would be invited to discuss childhood interventions and present opportunities, aims to transform parent perspectives on career-planning for autistic individuals. By helping parents perceive autism differently and focus on the strengths of their children, these neurodiversity seminars seek to reshape the way parents search for their children's extracurricular opportunities.

After adopting a strength-based mindset, parents would likely attempt to pursue the improvement and development of their children's existing talents, rather than focus on finding the "correct" or "most suitable" interventions—a notion that seems to be ingrained in Chinese perceptions about autism. To provide for parental desires to seek strength-based interventions, social service organizations that partake in social networking programs would then provide contact information for face-to-face services and local community providers and encourage parents to seek in-person consultation and guidance. Because the final objective of this policy seeks to bridge these connections between Chinese-American parents and local community providers, this policy proposes that local autism centers access Chinese-American families through anonymous social networking, especially in regions with significant Chinese-American populations.

To evaluate the effectiveness of the utilization of social networks in informing Chinese-American parents about American service provisions and encouraging Chinese-American parents to seek face-to-face intervention and advocate for their child, anonymous surveys will be issued to various parties of the implementation process, including the parents themselves, social service providers, and seminar presenters. These surveys invite parents to offer feedback freely in regards to the capability of social networks to provide not only accessible information but also stress relief in the process of navigating the unfamiliar American services system. The survey will also acquire a more quantitative measure of success through Yes/No questions about whether or not social networking influenced parents to seek out local autism professionals and community providers for face-to-face guidance.

Through an examination of the cultural and societal background from which Chinese-American parents of autistic children derive their perceptions of autism, the need for culturally tailored social services for these parents has become urgent and necessary. While more comprehensive steps can and should be taken, this policy proposal provides a first step to creating more culturally considerate environment in programs of social service providers for first-generation Chinese-American parents of autistic children.

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The Deceleration of Female Labor Force Participation

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Since the collapse of the Argentine economy in 2002 the country has experienced a severe deceleration in female labor force participation. While the recent leveling of the female labor force participation rate may suggest a natural rate has been reached, trends from the microdata suggest this is not the case. Since 2003, there has been an evident shift in the compositional makeup of the female working age population. The number of low educated women in the female labor force has fallen greatly as the number of middle and highly educated women continues to grow. Additionally, between these three groups, labor force participation increases drastically with greater educational attainment. Therefore, as women become more educated and transition to formal labor markets the labor force should approach the participation rates of the middle and high educated population. In addition, cross-section analysis of the wage elasticity of the labor supply of married women since 2003 reveals the growing dominance of the substitution effect over income effect for this group. This attitudinal shift of the married female population could prove critical to the continued growth of a resilient female labor force.

Introduction

Female labor force participation has been one of the most significant forces propelling economies around the world in the past century. In Argentina, the rise of the female labor force participation rate in the 1990's coincided with GDP growth that was sustained until the collapse of the Argentine economy, which culminated in a default on the country's public debt in December 2001 (figure 1, figure 2). According to the Argentine government's national estimates, the female labor force rose from 35.2% in 1992 to 50.31% in 2003. However, after the economy's GDP quickly recovered from the economic crisis the rapid rise in the female labor force abruptly came to a halt. In fact, it currently has a lower female labor force participation rate than most other Latin American-Caribbean countries and has the second lowest among peer countries (Gasparini & Marchionni, 2017; Mateo Diaz & Rodriguez-Chamussy, 2016). What is puzzling about the deceleration is that precipitators of increased female participation, such as a fall in the mean number of children per household and a rise in female education levels, were strong during this time (figure 3, figure 4).[1]

In this paper, I seek to address whether or not a resurgence of Argentina's female labor force participation rate is in sight. By turning to household survey data I break down changes in the female labor force since 2003. First, I analyze the female labor force by levels of educational attainment. Data reveals labor force participation is substantially higher amongst higher educated groups and while these groups are growing in size, low educated female workers still comprise the majority of the working age population. Next, I dissect labor force participation trends and identify a relationship between the female labor force participation rate and male unemployment that falls away as educational attainment rises. Lastly, I analyze the elasticity of labor supply of married women to understand how the income effect and substitution effect have manifested since the economic collapse. The results support the hypothesis that the female labor force participation rate has not reached a natural rate. The country appears to be emerging from a transition period as the labor force of married women shifts from a dominating income effect to a dominating substitution effect. This suggests that the traditional arguments of Cerruti (2000) and Gasparini and Marchionni (2017) are no longer sufficient for explaining female labor force deceleration. Instead, declining real wages throughout the economy since 2011 have hindered rising female labor force participation growth. In fact, in the absence of deteriorating real wages, a rate-of-change supply model predicts a increase of 1.813% in the married female labor supply since 2011. Therefore, falling labor demand appears to be counteracting positive compositional shifts in the female labor force.

Literature Review

Existing theories on the deceleration of the female labor force view changing economic and political settings following the economic default as the key forces counteracting positive compositional changes on the female labor force. The period from 1998-2002, known as the Argentine Great Depression, took a large toll on the country, with the poverty rate reaching 53% during this period (Cibils, Weisbrot, & Kar, 2019). Households were desperate for additional income and by entering the workforce, women could alleviate some of the pain. As economic conditions began to improve after the crash, ample social assistance was also provided under the Kirchner administrations that greatly aided the country's poor (Garganta, Gasparini, & Marchionni, 2017). The improved financial standing of these households can be viewed as one of the main forces keeping women from joining the labor force.

The economic literature supporting this claim is not limited to Argentina as the shift in female labor force trends occurred in many Latin American countries. By looking at the entire region it becomes clear how changing economic status affected female labor force engagement. Gasparini and Marchionni (2017) discuss the deceleration in female labor force participation across the region but state that the decline is particularly noticeable amongst

1 Busso and Romero Fonseca (2015) discuss the effects of these factors in addition to increased technological innovation that helped wives with households chores and therefore made it easier for them to enter the workforce.

Figure 1

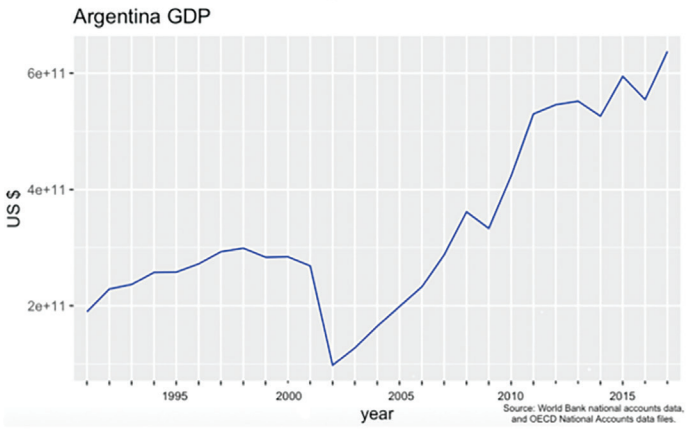


Figure 2

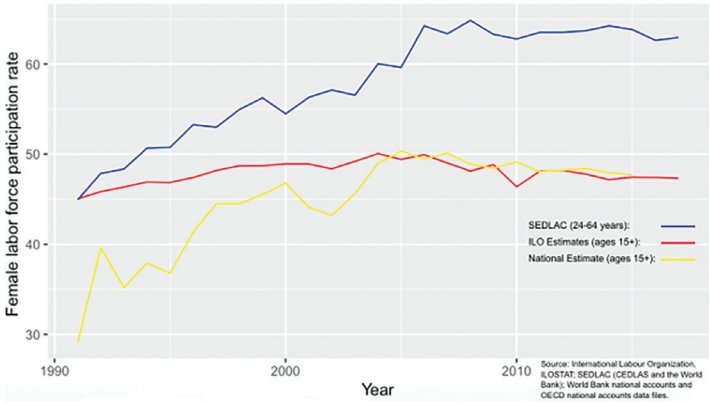


Figure 3

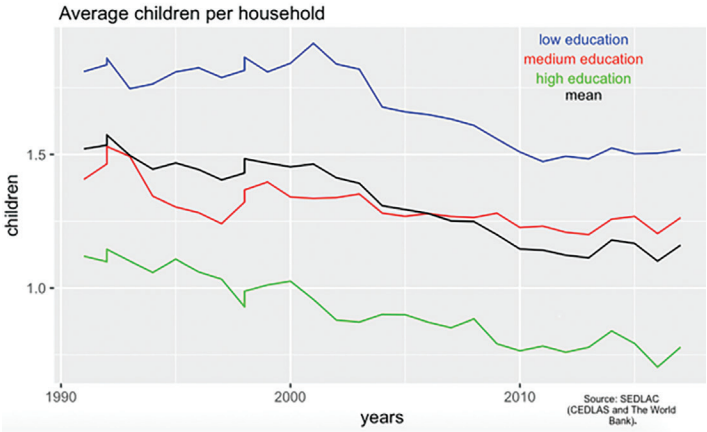
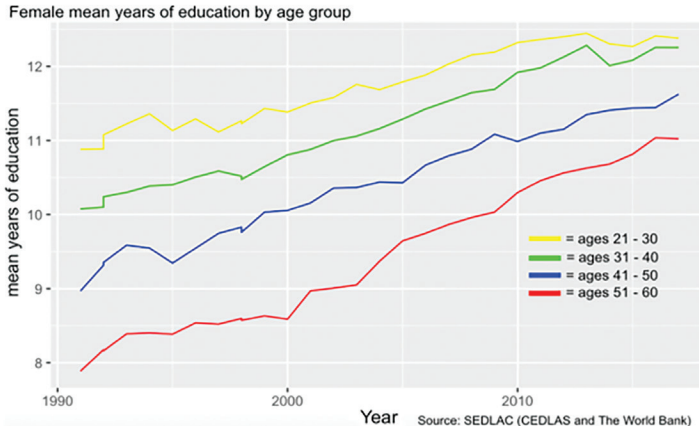


Figure 4



married and "vulnerable" women which they define as "women with low levels of education, living in rural areas, with children, and married to low-earnings partners". They claim the reason for this decline was an increase in transfer programs to low income households across the region and the improved economic status of their partners. In these cases, women were deterred from entering low quality jobs by their spouses. Similarly, Cerruti (2000) argues that female workers in Argentina in the 1990's were subject to an "added worker effect" in which other household members join the workforce when primary earners are unemployed.[2] This further supports the claim that as the economic standing of families began to improve, less women entered the labor force to compensate for the male head of the household's lost income.

The fall in labor force growth seems to support the theory of a U-shaped relationship between development and female labor force participation put forth by Goldin (1994). The theory claims that there is a correlation between female engagement in the labor market and economic development. In its simplest form, it means that in the poorest countries female labor force participation is high in order to provide additional family income. It then begins to fall in middle income countries as a strong income effect, promoted by a social stigma which looks down upon working in available manual labor jobs, starts to dominate. Furthermore, the theory suggests that eventually a switch occurs as as rising education and falling fertility rates make it easier for women to join the workforce. During this time, the income effect falls away and the substitution effect begins to dominate.[3] At this point, women enter more socially acceptable white-collar jobs.

Understanding where either a negative income effect or a positive own-substitution effect dominates the married female population can offer crucial information about whether the female labor force participation rate will continue to rise. If women decide to rely on the increased income of their spouses as opposed to deciding to work, then participation rates can expect to remain stagnant. Currently, Argentina sits toward the middle of this theoretical curve and begs the question of whether it will remain here or continue on a trajectory up the curve (figure 5).

Discussion on whether or not Argentina's female labor force has settled in center of this curve and reached its natural rate is limited. Yet, despite the limited attention the matter receives it is an increasingly pressing topic. The female labor force participation rate has stalled in the past decade and in looking at trends of the overall female labor market, no significant change appears to be approaching. Additionally, the country's current economic situation is dire with inflation rising 43.7% in 2018 and the poverty rate rising six percentage points to 32% in the past six months (INDEC,

2 Cerruti (2000) focuses on structural components of the female labor force in Argentina prior to the economic collapse in 2001.

3 The income effect is defined as a change in demand for a good or service caused by a change in real purchasing power. In this case, the good is the female demand for labor and the change in purchasing power is a change in the income of her household/partner. The substitution effect is defined as the effect a change in price or income has on the amount one consumes of a good. In this case, the good is the female demand for labor and the price is the real wage. If a negative income elasticity greatly exceeds a positive own-substitution elasticity than an equal rise in household/spouse wage and in own wage will result in a decrease in female labor demand.

Figure 5
GDP per capita v. female labor force participation rate (2017)

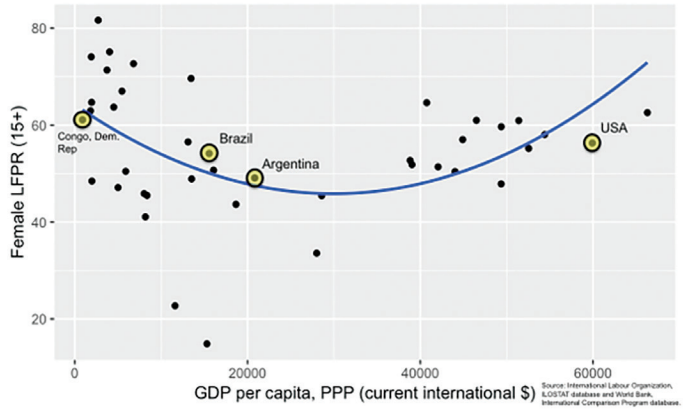


Figure 6
Argentina female labor force participation

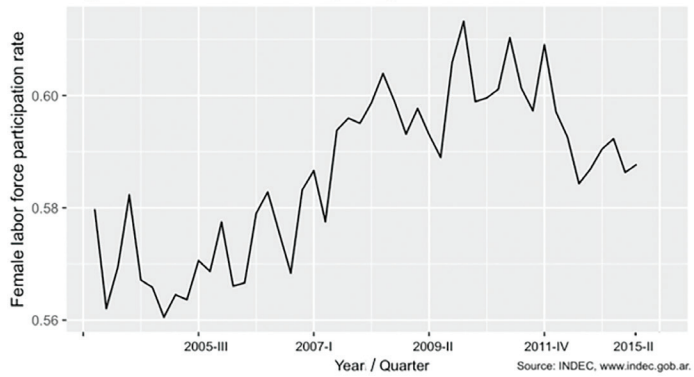


Figure 7
Argentina labor force participation

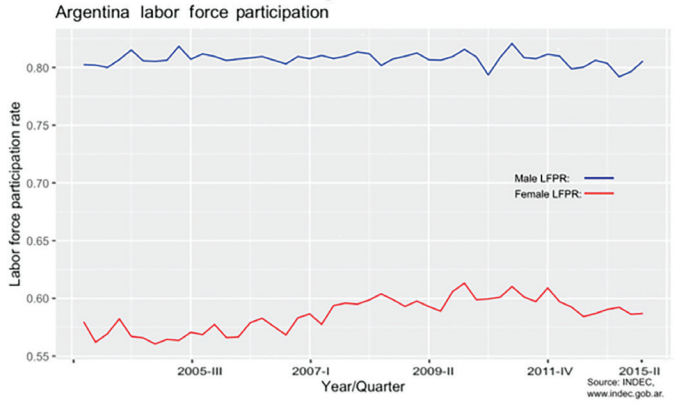
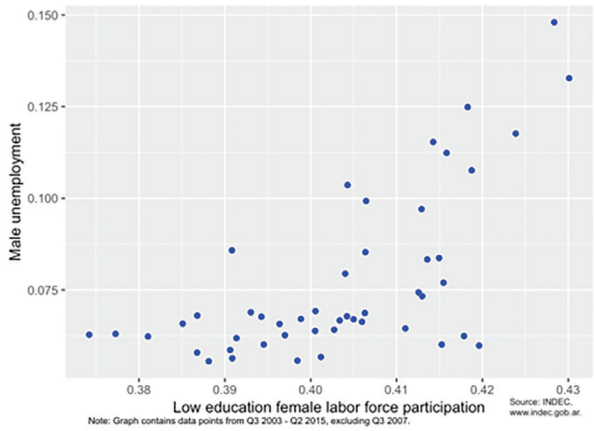


Figure 8
Low education female labor force participation rate v. male unemployment rate



2019). Following the Depression, the country instituted an ineffective economic development program with an expanded social safety net that helped the impoverished population while creating an unsustainable cycle (The World Bank, 2018). These changes acted against growth fundamentals such as a strengthening labor force that had been developing prior to the collapse and derailed positive economic development. At the present moment, the country is plagued with low productivity and in need of a boost. If the female labor force were to match the male rate it would increase per capita growth on average by one percentage point per year and contribute to the social security system.[4] [5] An end to the period of stagnation the female labor force has endured could provide desperately needed assistance to the country's economy.

Data

The data used in this study come from the *Encuesta de Permanentes Hogares Continúa* (EPH-C) from the third quarter of 2003 to the second quarter of 2018. The survey is a representative household sample which is gathered using multi-layered and stratified design and is administered quarterly by the Argentina's Instituto Nacional de Estadísticas y Censos (INDEC). The sample covers 31 large urban areas and represents over 60% of the country's population. It is divided into two data sets each quarter, one for individuals and another for households. This survey replaced the previous survey used by the INDEC, *Encuesta de Permanentes Hogares* (EPH). The EPH was used up until the first half of 2003 and differed significantly from the current survey. It was administered to a smaller portion of the population, was only administered twice a year and had a differently structured questionnaire.

Therefore, in an effort to maintain consistent labor force estimates without jumps in results due to methodological changes, the data analysis of female labor force trends is limited to 2003-2018. The data covers all quarters in the period with the exception of Q3 2007. Aside from this missing frame, the data set is ideal for analyzing trends in female labor force participation during and following the deceleration period. There are various elements that could confound results such as differing sample size from quarter to quarter, occasional input errors for data entries and biases towards lower income participants due to greater likelihood in responses from these households.

Trends in the Female Labor Force

Analyzing both general and education specific female labor force rates from 2003-2018 reveals informative trends regarding the female working population. Eligible members of the female labor force in this study are women who are over 15, are not students, are not making revenue leasing or renting property, are not retired or receiving a pension and are not disabled. Under this classification, the female labor force participation rate has followed the following trend since the Q3 of 2003 (figure 6). It has been subject to cyclical fluctuations, similar to the male labor force participation (figure 7).

4 The World Bank Group (2018) published a Systematic Country Diagnostic of Argentina that documents the positive effect the female labor could have on the country's economy based off of national household survey data.
5 Figure 7 demonstrates the difference between the female and male labor force participation rates.

Figure 9

Medium & high education female labor force participation rates v. male unemployment

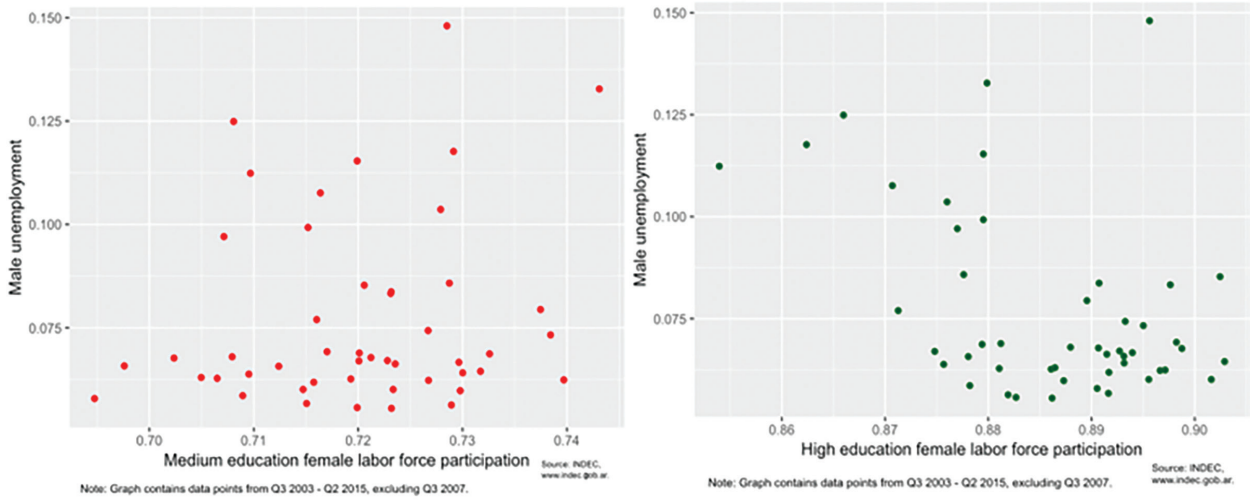


Table 1

Composition of the female labor force by educational attainment

Year	Low	Med	High
2003-III	57.51%	28.19%	14.30%
2004-II	57.29%	29.15%	13.56%
2005-II	56.84%	29.28%	13.88%
2006-II	55.37%	29.74%	14.90%
2007-II	53.11%	30.78%	16.11%
2008-II	51.42%	31.81%	16.77%
2009-II	50.82%	31.39%	17.78%
2010-II	49.66%	32.01%	18.33%
2011-II	49.08%	32.44%	18.48%
2012-II	47.64%	33.16%	19.20%
2013-II	46.61%	34.03%	19.36%
2014-II	47.24%	33.86%	18.90%
2015-II	46.77%	34.34%	18.90%
2016-II	44.79%	35.70%	19.51%
2017-II	43.15%	37.78%	19.06%
2018-II	41.46%	37.97%	20.57%

Source: INDEC, www.indec.gob.ar.

Table 2

Female labor force rate by educational group

Year	Total	Low	Med	High
2003-III	57.98%	42.84%	72.85%	89.56%
2004-II	58.23%	43.01%	74.31%	87.99%
2005-II	56.45%	40.43%	72.79%	87.60%
2006-II	57.75%	41.50%	72.32%	89.07%
2007-II	58.28%	40.34%	72.96%	89.40%
2008-II	58.66%	40.42%	72.12%	89.07%
2009-II	59.50%	40.40%	73.75%	88.96%
2010-II	59.31%	40.06%	71.70%	89.82%
2011-II	60.59%	41.10%	73.17%	90.29%
2012-II	60.11%	39.88%	72.28%	89.27%
2013-II	60.90%	40.27%	73.00%	89.32%
2014-II	58.69%	38.51%	69.76%	89.31%
2015-II	58.77%	38.68%	69.47%	89.05%
2016-II	62.85%	42.25%	74.49%	88.83%
2017-II	63.44%	42.67%	73.96%	89.65%
2018-II	65.29%	42.23%	76.51%	91.06%

Source: INDEC, www.indec.gob.ar.

However, the most notable trend is that the rate underwent a general increase until about 2011 when it ceased to rise. This description is in tune with the trends identified with the SEDLAC, National Estimate and ILO trends (figure 2) although the exact year in which the rise seems to end varies by source due to different definitions of labor force and different sample groups.

The declining growth of the female labor force participation rate in this period appears worrisome upon first glance. However, it can be understood more thoroughly by breaking down these changes according to educational attainment group. Looking at the composition of the female labor force by low, medium and high educational attainment reveals vastly different trends within each and suggests the deceleration is transient. Individuals are classified as "low educated" if they reported not completing a secondary education on the EPH-C. "Medium educated" are those that completed secondary school but did not graduate from university. "Highly educated" are those that graduated from university. Women who participated in the EPH-C were grouped into one of these categories and used to understand residual changes of the female labor force since Q3 of 2003.

The first important result from the data demonstrates how the composition of the female labor force has changed since 2003. Table 1 shows how a rising educational attainment has affected the labor force population. There has been a large decline in low educated workers since the beginning of this period. The percentage of low educated females that comprise the female labor force population fell from from 57.51% in Q3 2003 to 41.46% in Q2 2018 (-16.05%). Over the same period the percentage of medium educated females rose from 28.19% to 37.97% (+9.78%) and highly educated rose from 14.30% to 20.57% (+6.27%). A rise in educational attainment is widely considered one of the key cultural changes leading to an increase in the female labor force participation rate. As education rises, more sophisticated jobs are available to women and they are less likely to look down upon the position they accept.[6] However, trends in the overall female labor force participation rate suggest the rising education of the female population does not have a significant impact. The next critical result from this data indicates why this is not the case.

The second key result pertains to the labor force participation rate of different educational groups of the female working force population. Table 2 shows drastically different participation rates for each group. As education rises, the probability of participating

6 In Argentina, the informal labor market is predominantly comprised of low educated women (SEDLAS, 2018). Occupations in the informal labor market include working as a cleaner or nanny for a higher income household. As females attain higher levels of education they can accept less socially stigmatized jobs.

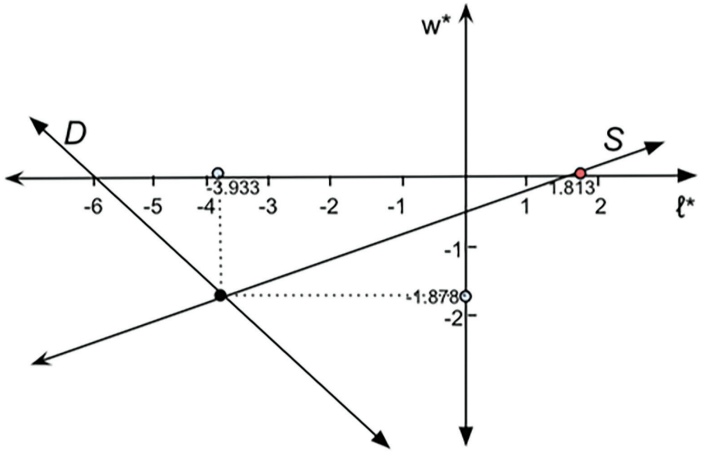
Table 3

Year (Quarter 2)	Argentine Peso to U.S. $ Exchange Rate (May of given year)	Deflated Average Married Female Hourly Wage (US$)	Deflated Average Married Female Weekly Income (US$)	Deflated Average 2 Spouse Weekly Income (US$)	Average Married Female Hours Worked / Week
2004	2.920	1.44	40.38	85.51	31.93
2005	2.892	1.67	47.63	102.75	31.45
2006	3.053	1.98	57.62	122.13	31.33
2007	3.081	2.51	73.56	158.40	32.48
2008	3.152	3.17	94.11	203.11	32.77
2009	3.839	3.28	95.29	196.55	32.25
2010	3.902	4.09	118.03	237.96	32.02
2011	4.084	4.82	143.07	279.93	33.10
2012	4.449	5.48	160.76	313.34	32.18
2013	5.236	5.67	162.69	316.48	31.78
2014	8.039	4.95	144.91	287.87	31.92
2015	8.948	5.94	172.00	330.36	31.48
2016	14.132	4.21	120.56	168.91	31.09
2017	15.695	4.72	131.62	226.72	31.80

Note: Prices presented in 2018 U.S. $ values.

Source: INCEC, www.indec.gob.ar & Información Económica al Día: Dinero

Figure 10



Note: This is a schematic representation for a general model of the married female labor market from 2011-2017. The equation for the rate-of-change supply curve is $\ell s^* = S^* + \eta w$ with $\eta = 3.090$ and $S^* = 1.813$. It was calculated using EPH-C data on the labor force participation and change in wages during this period to find the equilibrium point. The equation for the rate-of-change demand curve is $\ell d^* = D^* - \delta w$ with $\delta = -.9$ chosen for schematic purposes.

in labor markets also rises. High educated women exhibit the largest participation rate which remains consistently around 89% and are subject to low variability. Medium educated women also participate at a greater rate than the female average, around 72%, and are subject to more variability than the high educated women. Lastly, low educated women experience by far the lowest participation rate at around 40% and it are the most variant group during the period of analysis.

Additionally, the different rates appear to be motivated by different factors. Akin to the findings of both Cerruti (2000) and Gasparini and Marchionni (2017), fluctuations in the low educated female labor force population are correlated with fluctuations in male unemployment (figure 8). During periods of economic instability, as suggested by times when male unemployment is high, low educated females demonstrate the "added worker effect" by joining the labor force to counteract the lost household income of their spouses. Yet, the same relationship does not hold for higher educated groups as no clear correlation exists with male unemployment exists (figure 9). This begins to explain the differing attitudes towards work which develop throughout the general female population during the period after the economic collapse of 2002 that can be further explained through analysis of labor supply elasticities.

Results

A more fundamental understanding of what is driving Argentine women to work can be obtained by deriving estimates of labor supply elasticities for married women. While it is generally necessary for single women to work in order to generate an income and survive, married women are more likely to sit on the precipice of entering the labor force. Therefore, an attitudinal shift of married women can prove to be a key indicator of a rising female labor force. This information reveals a clearer vision for what the future of the female labor force participation rate. By looking at the income of married working women, the income of their spouses and the hours worked by these women from Q2 survey results of each year since 2004, estimates for the income elasticity and own-substitution elasticity can be found through cross-section analyses.[7]

Before beginning this analysis, it should be noted why a consideration of the income and own-substitution elasticities of the female labor force population is useful. Wage elasticities are normally examined over a much longer period of time. For instance, Goldin (1990) in her analysis of the married female labor force in the United States looks at how elasticities change over more than a century. Yet the period after the Argentine economic collapse merits a consideration of these elasticities given the incredibly rapid economic development that occurred in such a short amount of time. Note that the average deflated hourly wage of working married women in Q2 of 2003 was $1.43 and rose to $5.94 by Q2 2015 (table 3).[8] Because of this, the wage elasticity of married females, η, defined as change in weekly hours worked over change in hourly wage, changes rapidly year-to-year (table 4). It is therefore constructive to look at the ratio of the income effect to the substitution effect in order to determine which dominates the average married woman's decision to work.

The labor supply elasticities for each year were derived using cross section analysis and the Slutsky equation.[9] The Slutsky equation is defined as: $\eta = \eta_s + \alpha - \varepsilon$. The equation relates the uncompensated

7 Elasticity estimates were not included for Q2 2018 due to rampant inflation during this quarter, over 32.41% (INDEC, 2019), that confounds analysis of real price values.

8 Prices are deflated to 2018 U.S. dollar value.

9 See Goldin (1990, table 5.2) for greater qualification of this procedure.

Table 4

Year (Quarter 2)	Wage (Uncompensated) Elasticity [η]	Own-Substitution (Compensated) Elasticity [ηs]	Income Elasticity [- ε]	[α x ε]	Ratio of Income Elasticity to Substitution Elasticity [ε / ηs]
2004	9.097	10.695	-5.247	1.598	0.491
2005	6.928	8.438	-4.754	1.510	0.563
2006	7.778	9.325	-4.528	1.547	0.486
2007	6.194	7.653	-3.921	1.459	0.512
2008	4.537	5.543	-2.977	1.006	0.537
2009	4.697	5.822	-2.945	1.125	0.506
2010	3.234	3.922	-1.901	0.688	0.485
2011	3.596	4.142	-1.589	0.546	0.384
2012	3.145	3.642	-1.302	0.497	0.357
2013	2.784	3.252	-1.298	0.468	0.399
2014	3.690	4.361	-1.985	0.671	0.455
2015	2.935	3.542	-1.487	0.607	0.420
2016	3.211	3.685	-1.481	0.474	0.461
2017	2.070	2.342	-1.081	0.272	0.462

Source: INDEC, www.indec.gob.ar.

Note: The Slutsky equation, η=ηs - αε, is used to calculate the own-substitution elasticity. α = wife's weekly income / husband's weekly income.

wage elasticity, η, to three other terms:

:η_s, own-substitution, or compensated wage, elasticity
:-ε, income elasticity
: α, wife's full-time income divided by husband's full-time income

Cross-section estimates for the coefficients η, $-\varepsilon$ and α can all be generated using information collected from the EPH-C survey. The uncompensated wage elasticity estimate is found by running a regression on married female hours worked per week over married female wage, which is defined as reported weekly income from primary job divided by hours worked at that job in a given week. Income elasticity is estimated by running a regression on married female hours worked per week over spouse's wage, which is also defined as reported weekly income from primary job divided by hours worked at that job in a given week. Lastly, α is estimated by running a regression on wife's weekly reported income from her primary job over her spouse's weekly reported income from his primary job. The hope was that by only using information from primary work positions more consistent wage estimates would be derived however it should be noted that this could lead to errors in the estimates. In the end, the three coefficients found for Q2 in each year were used to calculate the own-substitution elasticity.

It is important to note that the estimates for the ratio of the income elasticity to the own-substitution elasticity are noisy. Given consistent fluctuations in currency value, as seen by the constantly changing exchange rate to the U.S. dollar, rapidly rising real wages, effects from social welfare policies that greatly assisted low income families and potential biases in survey sampling from year-to-year, there many factors are at play. Yet, while the ratios do not follow a completely cohesive trend, they do tell a story. The income and own-substitution elasticities battle for dominance up until 2008, after which the income effect never overwhelms the substitution effect again. The rise of the substitution effect supports the effects of compositional trends with regards to differing attitudes towards labor force participation exhibited by different educational groups. Less married women being motivated by the economic status of their husbands and becoming more incentivized by their own wages suggests the construction of a more resilient female labor force that can will not shirk in periods of positive economic growth.

If this is the case, then why has the female labor force participation rate seen a fall since 2011 according to both hourly estimates of married women and survey estimates for the entire population? To answer this question, one must turn to the changing real wages and real income of both married females and their spouses since 2011. In the period from 2011-2017 the real income of married females fell -1.878% while the average hours worked per week fell -3.933% (table 3). Additionally, the average uncompensated wage elasticity of married females was 3.090 (table 4). Using this information, a variant of the traditional supply and demand curves can be used to predict what labor force growth would have been in the absence of falling wages (figure 10).

In this model, the horizontal axis is the rate of change of labor force participation (average hours worked per week) and the vertical axis is the rate of change of married female income (weekly earnings).[10] The slope of the supply curve is the inverse of the average wage elasticity. The supply and demand functions can easily be derived from the following static supply equation:

$$\ell_s = [\, S' \, Y_m^{-\varepsilon} \,] \, w^{\eta}$$

$$\ell_d = D w^{-\delta}$$

where ℓ is married female labor force participation by weekly hours worked, Y_m is husband's weekly earnings, w is wife's weekly earnings, $-\varepsilon$ is the income elasticity, η is wage elasticity, δ is the elasticity of demand, S' includes factors affecting labor supply except Y_m and w and D includes all factors affecting demand except w. Taking logs of both sides of the equations and completely differentiating yields:

10 See Goldin (1990, figure 5.2) for greater qualification of this procedure.

$$\ell_s^* = [\, S' - \varepsilon Y_m^* \,] + \eta w = S^* + \eta w$$

$$\ell_d^* = D^* - \delta w$$

where $S^* = [S' - \varepsilon Ym^*]$. With this linear equation and the previously calculated coefficient values, it can easily be found that the change in labor supply would have been +1.813% in the absence of wage deterioration. The elasticity of demand was not calculated for the purpose of this calculation however in order for the equilibrium to hold the demand curve requires a negative intercept and therefore declining labor demand.

Conclusion

A common explanation for the deceleration of female labor force participation in rapidly developing countries is too simple. Many economists have published works stating that the improving economic stature of poorer households removes the need for the wife to enter the workforce and as a result, female labor force participation falls. Although it is a salient explanation that can be applied to many countries in Latin America prior to periods of economic development, it must be applied with caution. While this story may hold true for the low educated portion of the female labor force in Argentina, the entirety of the story is far more complex. As education rises in Argentina, the correlation between labor force participation and periods of economic instability begins to fall away. In the past 10 years as educational attainment of female has risen rapidly, the population group which the original story pertains to has shrunk.

There are greater forces at work that have curtailed the rise in the female labor force. A fall in economic productivity, translating to a fall in real wages, can be viewed as a primary factor preventing the rise in married female labor force participation. The mentalities dictating married women's approaches to work have been shifting, likely due to a higher level of education and more occupational opportunities. With the necessary economic stimulus, Argentina's could currently be pushing through the lower portion of the theoretical U-shaped curve of female labor force participation. However, the country is currently facing great economic strife that has prevented the market of female labor supply from reaching its potential. As opposed to viewing the female labor force as a potential cure to the country's economic difficulty, the economic turmoil has instead ailed the growth of the female labor force.

Although this may inhibit future rises of the female labor force, it is not the end of the story. Should the low educated portion of the female labor force continue to fall, convergence to both the medium and high educated labor force participation rates should also approach. Additional research can be conducted to understand what factors are driving the fall in wages across different industries to be able to more concretely interpret the effect on married women's decision to work. Further insight can also be drawn by looking at compositional changes within industries in order to better understand what the future may look like.

In conclusion, there is still much more to understand about the economic climate affecting the female labor market. All that can be said definitively is that the female labor force of Argentina still has room to grow.

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Evaluating Progress of China's New Urbanization Plan

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This paper examines the relationship between China's 2014-2020 New-Type Urbanization Plan (NTUP), designed to help the Chinese Government direct urban development, and economically sustainable—inclusive, consumption-driven, and ultimately self-reinforcing—urbanization and growth. It begins by surveying the history and political economy of urbanization in China to identify migratory patterns and consumption spending as key variables China must (and does) consider as it designs policies seeking to chart urbanization. The paper then identifies the Hukou internal passport system as the most important tool NTUP proposes using to manipulate migratory and consumptive patterns to achieve balanced urbanization. Having laid out the structures of China's urbanization concerns and NTUP, the study analyzes economic trends and Hukou policy reforms throughout NTUP in two mid-size cities: Dongguan, Guangdong and Yingkou, Liaoning. The key finding is that more sustainable urbanization has coincided with less liberal Hukou reform in Dongguan; conversely, less sustainable urbanization has coincided with more liberal Hukou reform in Yingkou. This finding is taken as an indication that sustainable urbanization may be more closely tied to variables exogenous to NTUP (such as pre-existing economic conditions) than it is to NTUP and related Hukou reform. Acknowledging the limitations of my own research, I propose a future investigation that could more definitively establish or rule out causal links among NTUP policy, migration, consumption, and economic growth.

Introduction

In the space of a few decades, China has become one of the world's most dynamic and productive economies. Since 1978, a large domestic labor force activated by foreign investment has created unprecedented economic growth and made China a global business and political hub.

As China has modernized, it has urbanized: cities have appeared, mostly near the coast, and attracted millions of migrants from underdeveloped areas. Migrants' concentration in major industrial centers has strained those centers' municipal resources and caused social strife.

Seeking to avoid such issues, China has attempted to manage future urbanization. Most of China's land and nearly half of its residents are still rural. The Hukou household registration system, a Mao-era relic, has long been leveraged to direct migration. The New Urbanization Plan (NUP), launched in 2014 for implementation through 2020, is the most recent state-managed urbanization policy. NUP aims to guide migrants towards under-urbanized cities with potential for growth. To that end, it proposes Hukou system reform and coordinated infrastructure development.

In this paper, I will examine NUP implementation and whether it has fostered sustainable urbanization and growth. I will begin by surveying Chinese urban history and the political economy of urbanization, to identify variables China must grapple with as it charts its path. I will then study the degree to which two cities—Dongguan, Guangdong and Yingkou, Liaoning—have, under NUP, used the Hukou system to manufacture economically sustainable urbanization. Ultimately, I will conclude that NUP Hukou reforms have been relatively ineffective in directing urbanization, which seems to follow patterns of economic development.

This research is timely: by 2020, China will need to publish the next steps in its urbanization strategy; framing next steps requires understanding NUP's practical urbanization implications. Moreover, it is important: China's urbanization policies affect hundreds of millions of migrant workers. Formulating policies that effectively promote well-being requires understanding migrant workers' behavior and needs.

Historical Context

Past Economic Development and Urbanization

In 1978, Deng Xiaoping introduced liberal economic reforms characterized by openness to foreign investment and markets. He initially restricted policy changes to select "testing ground" eastern, coastal cities called Special Economic Zones (SEZs). Among the initial four SEZs, Shenzhen was most open to global markets, and the most productive. Between 1980 and 1984, Shenzhen's economy sextupled as the SEZs collectively contributed to a Chinese economy growing 10% annually. SEZs' "demonstration effect[s]" inspired expansion of economically liberal policies, which have led to unprecedented growth.

Sustainability of SEZs' development was enabled by "an almost inexhaustible supply of cheap labor from rural China." Prior to SEZ designation, Shenzhen had only 314,100 permanent residents; by 2016 migrants had swelled that number to 11,908,000. Beyond Shenzhen, urbanization has swept China as migrants enter cities thriving on FDI and exports. By Guan Xinglian's account, in 2015, 56.1% of the China's population was urbanized, dwarfing 1979's <20% urbanization rate. Rural-to-urban migration has paralleled economic development.

As Wang & Maino emphasize, Chinese migrants respond to the "concentration of industries." Jobs attract laborers, and jobs are available where businesses have agglomerated—in cities. While Wang and Maino state that migrants prefer destinations near their points of origin, they say that the possibility of greater marginal earnings gains strongly incentivizes longer journeys. In 2011, the five highest-wage provinces were all coastal, while none of the bottom five were. This explains why up to 82.6% of Chinese migrant laborers have moved to the coastal regions that were comprehensively

urbanized by Deng's reforms.

Looney and Rithmire argue that migrants' flooding cities has led to unbalanced growth. Nationally, it has limited the geographic distribution of urban areas. In fact, China remains "under-urbanized" relative to its level of industrialization. Large cities have continued to grow; newer cities have struggled to attract migrants. Jaros notes that as larger cities develop, "urban and industrial growth elsewhere remains stunted." Unbalanced growth is self-reinforcing: as large cities grow and become ever-more attractive to migrants, smaller cities are increasingly left behind.

China's has responded to this imbalance with population management. For example, Shanghai, one of China's largest cities, has declared intentions to "control permanent population" size. The Hukou system exists as a formal institution to exert such control.

The *Hukou* System and Chinese Urbanization Goals

The Hukou system is a national household registration system. Originally instituted in 1958, it was designed to reinforce the agricultural supply chain and allocate labor resources favorably for the CCP. Apparently modeled after the Soviet propiska internal passport,[1] it aimed to tie rural agricultural workers to their farms and supply urban industrial workers with food and other natural resources.

Today, the Hukou system is implemented to control migration. According to Chan, under the Hukou system, citizens are entitled to public benefits in their regions of origin; relinquishing Hukou status in a certain region entails leaving associated benefits behind. Rural benefits include farmland entitlements. Urban residents receive social services such as education, medical care, and pensions. Historically, changing one's Hukou registration, inherited from parents, has been administratively complicated. The value of public entitlements distributed according to Hukou status has thus made the Hukou system a relatively efficacious tool to direct migration.

The CCP seeks to control migration to reduce the stress migrants place on urban society. Looney and Rithmire note that overwhelming migration to cities has resulted in "urban sprawl, conflict over land rights, local government debt, and substantial inequality." Migrants can strain public finances, particularly when given expensive entitlements like medical care. They also tend to aggregate in slum-like semi-permanent urban "villages," which threaten China's modern global image. Finally, migrant communities might collectively mobilize, threatening social stability. Sudworth points out a 2012 migrant riot in Shaxi, Guangdong in which police exerted "overwhelming" force to reestablish order before calling for greater "social management" to prevent similar outbreaks.

While Hukou restrictions discourage rural-to-urban migration, they do not prevent it.[2] As of 2016, China officially had an estimated 245 million migrant laborers, overwhelmingly rural-to-urban, living and working outside of their Hukou registration localities.[22] This population, commonly referred to as the "floating population," is generally concentrated in the largest urban areas, such as SEZs and their surrounding regions.

Migrants struggle to integrate into urban societies, potentially undermining cities' economic potential. Wang & Maino note that migrants tend to work "dirty, dangerous, and demeaning" jobs and live separately from locals. These conditions contribute, per Babones, to a perception among urban locals of migrants as a "socially excluded underclass." Better urban integration of migrants—potentially facilitated by Hukou reform—may be necessary for sustainable economic development. Balanced and socioeconomically integrated cities would facilitate China's shift to a domestic demand-driven economy.

The 2008 financial crisis exposed export-oriented growth's vulnerability to international economic volatility. Responding in 2011, China's then-Vice-Premier Keqiang Li saw securing domestic demand as an "essential requirement of…economic development on a long-term basis." Policy has reflected Li's priority. The 2016 13th Five Year Plan, currently being implemented, urges "great energy" be spent generating domestic consumer spending. Similarly, the 2017 update on economic progress notes the value of "expansions in aggregate demand." While international spending has fueled growth in China, stabilizing growth calls for domestic spending.

Urbanization is connected to domestic consumption. Li noted cities as having the "greatest potential for boosting domestic demand," highlighting urban areas' high per capita consumption. Elaborating, he advised "rais[ing] the income level of low earners" and "establishing a social safety net" to stimulate consumption. These steps could erode the "intra-urban dualistic structure" separating locals from migrants to speed the "unlocking [of] the potential domestic demand brought about by urbanization."

The challenges Li highlighted as preventing sustainable urbanization are exacerbated by the Hukou system. Chan explains that deprivation of public benefits makes migrants' wages "effectively lower," reducing their spending capacity, differentiating them from urbanites, and preventing their social integration. Chen concludes that granting migrants local Hukou—or, at the very least, granting them access to the benefits Hukou holders enjoy—could be "the easiest approach to increase their consumption." There appears to be conflict between the Hukou system and China's stated economic goals.

The New Urbanization Plan and Contemporary Policy Debate

China's New Urbanization Plan (NUP), devised for implementation from 2014-2020, takes a "people-centered" approach to reducing the above conflict. Intended to stimulate balanced urbanization, NUP calls for updates to the Hukou system and improved social welfare.

Recognizing migrant workers as a "mainstay" of urban areas, NUP asks municipalities to accelerate their urban "citizenization," that is, the process by which they obtain urban Hukou registrations and access to entitlements. Expanding migrants' access to welfare would effectively raise their incomes and spur domestic demand across China.

More broadly, NUP is meant to "restore the population registration management function of household registration" to help the

1 Cynthia Buckley offers a concise, compelling history of the propiska system. Like Hukou, it was implemented to give the State control over migration; it is widely held to have been ineffective. The failure of the Soviet system begs the question: is can Hukou succeed where propiska failed?

2 The Hukou system has prevented migration in the past. Between 1960 and 1976, for instance, its strict enforcement curtailed rural-urban migration. Jason Young's comprehensive history of the Hukou system explores how its effectiveness has changed according to stringency of enforcement. See page 182.

CCP direct urbanization across the country. To that end, NUP specifies how to coordinate Hukou reform. It directs small towns and cities to liberalize Hukou registration drastically. Megacities are directed to strictly limit registration. Medium and large cities are advised to take a middle path, liberalizing registration systems moderately. Officials hope migrants will enter smaller cities and relieve pressure on larger cities; relaxed Hukou registration restrictions are expected to lure migrants accordingly.

NUP also advises local governments to prepare for "huge investment demands of building urban infrastructure." To accommodate expected migrants, NUP calls for infrastructure development in under-urbanized areas targeted for growth. Within smaller cities, special industrial neighborhoods are being created to attract business and create jobs. Public service provision systems are being expanded. Rural land around planned urban expansions is being expropriated for repurposing into housing and business infrastructure.

It remains to be seen whether smaller urban areas will indeed agglomerate successfully. Businesses need to concentrate, migrants need to arrive, and urban populations need to be socially integrated for the ultimate goal—increased domestic demand—to be achieved.

NUP's Hukou reform proposals are acknowledged as central to sustainable growth. The World Bank notes that tying welfare access to exclusive Hukou status prevents "social inclusion of migrant populations, financially and politically," yielding "social stratification.". Integrating migrants into public welfare systems could represent a wise long-term investment: "every yuan of incremental public spending on health results in a 2 yuan increase in the consumption of urban households." Not only is liberalizing Hukou reform in migrants' interests, it is in municipalities' economic interests.

That said, NUP's plans to funnel migration into smaller cities by coordinating Hukou reform may be misled. The China Development Research Foundation notes that large cities tend to be more desirable to migrants. Despite CCP intentions, attempting to prod migrants towards smaller cities may "simply not [be] in accord with the realities" of urbanization. In any case, allowing continued growth in large cities could be economically desirable.

Edward Glaeser sees crowded cities as positive features. Poor migrant communities only expand because cities successfully offer economic improvement. While large cities are assets to migrants, migrants are assets to large cities: "urban density makes trade possible; it enables markets." Keeping migrants away from larger cities might undermine consumer markets rather than consolidate them. In agreement with Glaeser, Klaus Desmet and Esteban Rossi-Hanberg predict that welfare would increase were China's existing megacities allowed to expand. NUP's emphasis on moving migrants towards underdeveloped urban areas may be counterproductive to national economic transition.

Meanwhile, relaxing Hukou registration and welfare restrictions in small cities to attract migrants may be futile. Rural migrants are apprehensive to pursue permanent residence in smaller cities. In 2011, Zhongshan, outside of Shenzhen, relaxed Hukou requirements, convincing only 100 migrants to obtain local Hukou registration out of 30,000 eligible. Chuanbo Chen and Cindy Li attribute this to the depreciating value of urban Hukou due to the instability of migrant lives in urban spaces. Migrants may be unwilling to bet on integration and stability in unestablished areas, regardless of HuXkou incentives.

NUP's call for infrastructure development to accompany Hukou relaxation is also contentious. Expanding public welfare distribution, transportation, and housing infrastructure is expensive, and the World Bank notes that the "overwhelmingly local" costs may be difficult for municipal governments to bear. Moreover, given unpredictable migration implications of Hukou reform, investment may be premature.

Michael Pettis agrees in his admonishment of China's strategy of "forcefully urbanizing." Criticizing the strategy of artificially pulling migrants and investment to underdeveloped urban markets, he explains that "urbanization itself responds to growth;" it does not generate growth. Pettis proposes that, in emphasizing urbanization's potential to 'unlock' economic development, the CCP has mistaken the effect for the cause. Indeed, the Party appears to have misunderstood this relationship in the past: Looney and Rithmire highlight China's many empty modern "ghost cities," built up and unpopulated. Migrants can increase cities' productivity. Paradoxically however, only a productive city will consistently entice migrants.

Chinese officials appear to disagree, confident that policy planning alone can lure migrants. As early as 1998, Mayor Niu Yuru of Baotou, Inner Mongolia insisted that "a good city image will have an important impact on improving the city's visibility, expanding contacts, and promoting urban economic development." From his perspective, migrants are enticed by cities that demonstrate commitment and capacity to accommodate them. Demonstrating commitment and capacity—cultivating a 'good city image'—involves, largely, expanding access to Hukou-restricted welfare distribution infrastructure. NUP was conceived with the same set of assumptions.

The above perspectives on coordinating Hukou reform to spur urbanization-driven growth are valuable insofar as they might affect policy and planning. That said, they have not yet been contextualized and evaluated within the NUP policy context. I investigate NUP evidence in two cities to do just that. My focus is how migrants have responded Hukou reforms aimed at luring them to smaller urban areas. I evaluate whether and to what degree commenters like Pettis, skeptical of the possibility of urbanization creating growth rather than reflecting it, have successfully anticipated the recent course of Chinese urban development. Several years into NUP, I aim to present an early retrospective.

Research Design

Case Selection

I evaluate two cities' attempts at NUP Hukou reform designed to direct urbanization and demand-driven economic transition under NUP. I examine both success—Dongguan, Guangdong—and failure—Yingkou, Liaoning—to try to differentiate effective and ineffective implementation.

To understand the interaction between urbanization and economic growth, I have chosen cities that initiated their NUP urbanization pushes in 2014 at different economic stages. Dongguan, Guangdong had a 596.59 billion yuan, heavily industrial economy growing at 8% per year. Yingkou, Liaoning, had a smaller economy of 159.11 billion yuan, growing relatively slowly at 6% per year. These cities have otherwise similar profiles. Both were targeted by their provinces for expansion, both are positioned near the coast, and both are heavily industrial. Additionally, both are prefectural-level cities, administratively only below their provincial

governments. Having chosen cities from different provinces, I aim to establish relationships applicable to urbanization across China, rather than findings specific to one province's NUP campaign.

NUP Success in Dongguan, Guangdong

As NUP began in 2014, Dongguan had 8.34 million residents; of these, 1.19 million had local Hukou while 7.15 million were not locally registered. Though a city of 8 million is large by most metrics, Guangdong has grown Dongguan under NUP. Positioned between Shenzhen and Guangzhou, Dongguan has been used to relieve population stresses on these larger cities. Dongguan officials have striven to cultivate an affluent, consumptive local population.

Anticipating increasing local affluence, the South China Mall (SCM) opened in 2007. Intended not to attract but to accommodate incoming Dongguan residents, SCM was expected to foster exchange independently of foreign investment. The world's largest shopping mall in terms of total commercial space, SCM initially flopped. In 2013, over 90% of leasable storefronts were vacant and the "ghost mall" gained international notoriety as an infrastructure development failure. Today, however, a rebranded and renovated SCM is almost fully occupied, fostering an active commercial environment.

SCM's delayed success reflects a gradual increase in local consumer demand, paralleled by migrants' arrivals and Hukou registration. Between 2014 and 2017, total annual consumer good sales in Dongguan increased from 1,615.29 billion yuan to 2687.88 billion yuan, a 66% increase. Over the same period, Dongguan simultaneously added about 90,000 residents and more than doubled the percentage of residents with local Hukou. By 2017, Dongguan had 8.43 million residents, of whom 2.11 million had local Hukou. Dongguan has successfully attracted and integrated migrants into relatively affluent urbanity, potentially modeling sustainable urbanization in the city and country.

NUP Failure in Yingkou, Lioaning

When NUP was launched, Lioaning Province's coastal Yingkou had 2.45 million residents, 2.33 million of whom had local Hukou. Non-Hukou migrants made up a small proportion of the population, particularly in comparison to Dongguan—less than 0.5%. Liaoning Province directed Yingkou to proceed with NUP by opening itself to migrants.

The city was seen as a promising site for urbanization: its underutilized port offers the potential to expand international business, which might attract workers. Simultaneous implementation of the Belt and Road Initiative (BRI), designed to boost China's international economic engagement, reinforced hopes of prosperity centered around the port.

Housing development began, pre-empting migrants' arrivals and home purchases. But as BBC reported in 2016, the developments remained vacant. Even shrewd investors were fooled: China Vanke, the world's largest home developer, built Harbour City housing community, which has stayed mostly vacant. Harbour City seems successful in comparison to developments like the 900-unit Seaside Village, hopelessly abandoned before construction was completed.

Housing developers anticipated increasing local demand throughout NUP. But consumption in Yingkou has not changed noteworthily over the course of NUP. Between 2014 and 2017, retail sales only increased by 21.53%, from 43.65 billion to 53.05 billion yuan. While substantial, Yingkou's increase pales in comparison to Doungguan's and China's (34.71%) for the same period.

Yingkou's failure to increase consumption throughout NUP parallels its failure to attract migrants. Over the course of NUP implementation, Yingkou has lost residents, falling to 2.44 million people. The city has also failed to increase the degree to which it extends Hukou registration to migrants: in 2017, 2.32 million Yingkou residents had local Hukou, representing roughly the same proportion to the general Yingkou population as they did in 2014. Granted, the percentage of Yingkou residents lacking local Hukou is and has been exceptionally small—there was relatively little room for improvement in that regard.

Economic Indicators for Dongguan and Yingkou Before and During NUP

Metric	Dongguan			Yingkou		
	2014	2017	%Δ	2014	2017	%Δ
Resident Population (million people)	8.34	8.43	1.08	2.45	2.44	-0.41
Hukou	*1.19*	*2.11*	*77.31*	*2.33*	*2.32*	*-0.43*
non-Hukou	*7.15*	*6.32*	*-11.61*	*0.12*	*0.12*	*0*
GDP (billion yuan)[iii]	596.59	758.21	27.09	159.11	128.83	-19.03
Consumption (billion yuan)	1615.29	2687.88	66.4	43.65	53.05	21.53

Information drawn from 2014 and 2017 municipal statistical bulletins.

Research Method

I compare Dongguan and Yingkou's NUP implementation at both planning and execution stages to determine the influence of NUP policies on urbanization outcomes. I limit my comparison to initiatives related to Hukou reform and integration of migrants into urban societies. Urbanization depends on the movement of people, and the Hukou system is China's best-established tool to shape such movement. Moreover, the connection between Hukou registration and access to local benefits means that locally registered migrants are more likely to consume; consumption motivates China's urbanization campaign.

First, I examine Dongguan and Yingkou's 13th 5-Year Plans, published during NUP, to determine how officials frame migration and urbanization. I evaluate whether Dongguan and Yingkou establish similar objectives for urbanization campaigns. These plans, published in 2016, are not local governments' first responses to 2014 NUP. They are nevertheless worth examining because they offer governments' mature insights on NUP following a couple years of experience with the policy.

I also study these cities' NUP implementation. I consider legislative reports and official forms relating to migrant integration into Dongguan and Yingkou. These documents reveal whether officials are enacting the strategies they outline for themselves.

Having compared Dongguan and Yingkou's NUP implementation, I offer reasons for their contrasting results. Similarities in their plans and implementation suggest that forces exogenous to NUP policies shape migration and urbanization. My focus on urbanization as shaped by Hukou reform does not account for influences

3 GDP information for Yingkou may be unreliable. Struck by the rapid GDP decrease shown in the data, I cross-checked several years of Yingkou's municipal economic publications with Liaoning Province's city-by-city statistical accounts; vastly different numbers were reported. I have chosen to report Yingkou City's official figures because I had access to more recent data, and because I had used the equivalent source to report Dongguan's statistics. That said, Dongguan's data is mostly consistent between municipal and provincial sources.

such as energy management, international relations, and climate change. Nevertheless, I hope to improve understanding of one major aspect of NUP and state-managed urbanization.

As I interpret data, I consider key differences between Dongguan and Yingkou. Dongguan's surrounding region is more populous and urban than Yingkou's. Moreover, Dongguan's recent urbanization push started with a better-consolidated local economy than did Yingkou's. I hope these differences enrich my analysis. These points of contrast allow me to consider different angles in accounting for variations in success urbanizing. NUP is a nationwide initiative; understanding implementation strategies requires studying the diverse contexts in which it is being enacted.

Findings

NUP in 13th 5-Year Plans

Dongguan, Guangdong

Dongguan's plan frames urbanization as a "new growth engine" for the local economy. Urbanization is noted for "agglomerating quality [economic] assets," both productive and consumptive. Increasing consumption motivates Dongguan's NUP implementation.

Reaffirming "people-centeredness" as crucial to urbanization, the plan calls for relaxing local Hukou registration requirements. Moreover, the plan proposes broadening public service and welfare access to non-Hukou residents. That said, it suggests limiting benefit access to longtime local residence permit holders. Residence permits are non-Hukou forms of local registration. These conditions would delay migrants' enjoyment of benefits other locals enjoy, indicating apprehension in Dongguan's integration of migrants into the local economy.

The rhetoric within Dongguan's plan indicates understanding of the importance of migrant integration to sustainable urban development, and clear but limited commitment to fully integrating migrants.

Yingkou, Liaoning

Yingkou's plan similarly reflects commitment to sustainable growth. Urbanization is cited as central to the city's "comprehensive [economic] revitalization." Revitalization is noted to rest particularly on the contributions of migrants to the local industrial sector. Like Dongguan's, Yingkou's vision for growth hinges on broadening migrants' roles locally.

Also like Dongguan's, Yingkou's plan calls for migrant integration with "people at its core," focused on improving migrants' quality of life. Because public benefits are closely tied to Hukou status, lifestyle improvements are linked to Hukou reform. The plan recommends reducing Hukou registration criteria to proof of migrants' employment and residence in Yingkou. This strategy would make full urban benefits to many new migrants, easing their integration into local life.

Dongguan's and Yingkou's plans frame urbanization similarly. Both prioritize attracting and integrating migrants into local economic systems to stimulate growth. To that end, they propose relaxing Hukou registration criteria. That said, Dongguan's reform proposals are more exclusive than Yingkou's. Dongguan's plan would allow only longtime residents to register; Yingkou appears prepared to integrate migrants into local society less discriminatorily.

Given this difference, Dongguan's greater success in attracting migrants is puzzling. It begs the question: have both cities followed their own Hukou reform agendas, or has implementation strayed from plans?

NUP Implementation

Dongguan, Guangdong

Dongguan's Hukou registration restrictions have been relaxed per stated objectives. Changes have simplified the process by which migrants in Dongguan register locally and access to public services.

Beginning in 2011, migrants looking to transfer Hukou registration to Dongguan faced a complex, multi-step process. Upon arrival, migrants were expected to obtain residence permits granting them limited access to public welfare. Permitted migrants would be granted Dongguan Hukou pending accumulation of "points," awarded according to credentials such as university education or military service. Pre-NUP regulations set 130 points as the minimum to earn registration, an unreachable threshold for many uneducated, poorly connected migrants.

Under NUP, Dongguan's migrant integration has changed. Following recommendations that medium-sized cities lower barriers to migration, Dongguan swiftly lowered its Hukou registration point threshold to 100. While the revised system kept Hukou benefits exclusive, the lower point threshold represented an effort to make urbanity more accessible to migrants.

In 2018, Dongguan eliminated the point system entirely. Under current regulations, any migrants who have held local residence permits and contributed to social security for five years may receive Hukou. Many migrants lack residence permits, and the required five-year local residence period without full access to benefits is challenging for many families seeking to move. Nevertheless, the elimination of the point system has further broadened migrant access to Dongguan Hukou benefits thereby facilitating their local integration.

Yingkou, Liaoning

Yingkou has enacted its own plans to integrate migrants into city life by broadening access to local Hukou. After publishing the 13th 5-Year Plan, Yingkou released revised Hukou registration requirements. Today's migrants may obtain local Hukou simply by purchasing a home. To be sure, many low-skilled, uneducated migrant workers lack the resources to purchase or lease homes. That said, Yingkou does not discriminate amongst migrants based on credentials or other qualifications; though financial obstacles to Hukou registration remain, most political and bureaucratic obstacles have been removed.

Beyond Hukou, in 2018, the Liaoning Government granted residence permit holders full access to public welfare systems in Yingkou. Residence permits are intermediate forms of housing registration that precede and are more easily obtained than Hukou registration. Previously, permit holders had been eligible only for certain public benefits. This change reduces the significance of Hukou registration itself within Liaoning. It accelerates Yingkou's integration of migrants into urbanity. Economically, it allows them to benefit from state support systems as they engage with the local market.

Evaluation and Analysis

In accordance with their 13th 5-Year Plans, both Dongguan and Yingkou have broadened migrants' access to Hukou registration

and public benefits.

That said, Dongguan's initiatives have been less liberal than Yingkou's. While Dongguan requires Hukou applicants to have lived and paid social security locally for several years, Yingkou accepts Hukou applications from any financially self-sufficient migrants. Moreover, unrestricted public benefits extended to Yingkou residence permit holders exceed the limited benefits Dongguan residence permit holders receive.

As was previously explored, greater inclusion of migrants is connected to their increased spending. Indeed, the 5-Year Plans published by both cities predict that relaxation of Hukou restrictions facilitates migrants' participation in local economies, ultimately generating growth. This relationship, however, only holds if migrants arrive.

Loosened restrictions were wrongly expected to incentivize migration to Yingkou—empty housing developments stand as evidence. And despite Dongguan's relatively restrictive Hukou and benefit system, migrants have consistently arrived and consumed, giving life to SCM.

Why, if Yingkou has implemented NUP in a manner more inclusive of migrants, has it failed to attract migrants and spur growth? On the other hand, how has Dongguan attracted migrants and increased consumption with a more restrictive Hukou registration scheme?

That NUP implementation in Dongguan and Yingkou has yielded seemingly counterintuitive results suggests that forces exogenous to NUP implementation shape Chinese urbanization today. I propose that Dongguan and Yingkou's urbanization paths have been more closely associated with their contrasting economic stages in 2014 than with NUP policies.

In many senses, Dongguan and Yingkou are comparable. Both are positioned near the coast and international borders. Both have heavily industrial economies. Both have been identified as urbanization candidates. Among their most salient differences—and the one with the most comprehensive data set—is their vastly different levels of economic success.

Dongguan's economy has dwarfed Yingkou's since before NUP implementation. As mentioned above, Dongguan's output was 3.5 Yingkou's in 2014. By 2017, the difference between them had increased: Dongguan's 758.21 billion yuan output was 5.86 times Yingkou's 128.83 billion yuan output. Counterintuitively, while Dongguan's economy has far outpaced Yingkou's, its official employment statistics have not. In 2017, 2.24% of registered Dongguan residents were unemployed; in Yingkou's unemployment was close behind at 3.01%. As percentages of total local populations, 79.16% of 2016 Dongguan's residents were employed, while 78.75% of 2015 Yingkou's residents were employed. According to official estimates, only about 20% of either city's residents are not economically productive. Migrants in both cities are apparently likely to find work.

That said, employment in Dongguan appears to be more sustainable than employment in Yingkou. Of workers employed in Dongguan urban units, or registered businesses, 1.81% were involved in construction. In Yingkou—the smaller, more slowly growing city—9.69% worked in construction. These statistics show that a significant portion of Yingkou's workforce has continued to build the infrastructure experience shows may not be filled until the economy vitalizes. Investment and employment in this sector are unsustainable long-term. Even in the short term, work in Yingkou may not be as desirable as work in Dongguan. Recent data show that Dongguan's workers earn 17.48% more than Yingkou's, on average. Jobs in Dongguan are more lucrative, and therefore potentially more attractive to migrants.

Contrary to NUP authors' expectations, migrant workers appear to be moving towards sustainable commercial activity, regardless of ease of access to welfare systems. This evidence reinforces Pettis' theory, highlighted above in the discussion of relevant literature, that urbanization merely responds to economic activity and cannot be manufactured to generate growth. Yingkou planners had this causal mechanism reversed when they relaxed Hukou restrictions and built excess housing capacity with the expectation of migrant arrivals. Dongguan's planners may have made the same mistake when investing in the world's largest shopping mall; the mall appears to have ultimately not because of city planning shifts but because the city already had a firm economic base with which to attract migrants, even if only gradually.

A comparison of pre- and mid-NUP resident populations in Dongguan and Yingkou would have helpfully illuminated evolution in migration trends over time, potentially relating to policy initiatives. Unfortunately, this data was not available for Yingkou, where only registered population was reported until 2014. In Dongguan, the average population increase year-to-year stayed consistent before and during NUP. Between 2011 (when the Hukou point system was established) and 2014, average yearly population change was 0.37%. Between 2014 and 2017, average yearly population growth was 0.35%. Migration seems to have been relatively insensitive to NUP policy shifts.

My analysis suggests that Dongguan's and Yingkou's success urbanizing over the past several years has corresponded more with economic performance than with NUP policy initiatives. These findings seem to apply to other cities implementing NUP. Since its unsuccessful Hukou relaxation in 2011, discussed earlier, Zhongshan, Guangdong, has been able to urbanize successfully drawing on its own industrial base. Meanwhile, Ordos, Inner Mongolia has struggled to populate Kangbashi, an attractive, modern urban development lacking a firm economic base.

If migrants seem to be motivated by market opportunities rather than Hukou incentives or disincentives, is NUP viable as a state-managed urbanization policy? Do the Hukou system and welfare access have future roles in controlling migration?

Further Methodology and Conclusion

Further research is necessary to understand dynamics with which NUP implementers must contend. As a first step, I would seek better understanding of the differences between Dongguan and Yingkou's economic profiles. Only after understanding differences in the economic opportunities the cities offer migrant workers could I evaluate those opportunities' significance in attracting migrants. Afterwards, I would work with migrants to determine whether the established connection between economic development and migrant arrivals is intentional or coincidental.

Dongguan and Yingkou's economies require closer comparison to differentiate opportunities they offer migrants. As Dongguan's economy dwarfs Yingkou's by most metrics, their comparable employment levels are notable—and suspicious. As a preliminary step, I would conduct surveys to verify official population, employment, and wage data. I would complement this process with a survey of informal employment in both cities. Though official statistics do

not account for informal employment, it is an important source of migrant workers' income—contributing up to 60%, in 2010—particularly in developing economies.

Having confirmed these data, I would measure the implications of employment opportunities in both cities. I would compare cost of living in Dongguan and Yingkou to determine the significance of the wage gap between the two cities. I would also gather energy consumption, nighttime light emission, and cellphone penetration data among workers as proxies for their affluence. These data, which may be used to cross-check each other, could be collected without consulting potentially dishonest government sources. The indicators are relevant because employment only represents meaningful economic opportunity if it improves employees' affluence and well-being; I will quantify affluence associated with employment.

Having quantitatively differentiated migrants' economic opportunities in Dongguan and Yingkou, I would interview migrants themselves to understand if and how these opportunities affect their decisions to move to urban areas. I would focus typical non-Hukou migrants: lower-class, less-educated workers.

First, I would first meet with randomly-selected migrants fitting my description from Dongguan and Yingkou. I would ask them why their hometowns were unsatisfactory. I would follow up by asking which cities they considered moving to, and how they ultimately chose their destinations. My questions would be targeted at (1) understanding how cities' economic opportunities were factored into calculations, and (2) understanding how Hukou restrictions were factored into calculations. To test for the importance of present levels of economic development versus potential future growth, I would ask whether BRI implementation in a potential destination city might have inclined them to move there. As an easy test for the allure of Hukou registration, I would ask migrants whether they planned on registering for local urban Hukou if they were to become eligible. I predict that economic opportunities in potential destination cities at the time of migration would prove to have been the foremost factor in migration decisions.

Next, I would meet with randomly-selected potential migrants outside of these cities, in: (1) the cities Dongguan and Yingkou are meant to relieve pressure on (Shenzhen and Dalian, for instance), (2) rural areas around Dongguan and Yingkou, and (3) Dongguan and Yingkou residents' hometowns. This diversity of interviewees would give me perspectives from an array of NUP policy targets. I would ask them about potential destination cities, and what factors might affect considerations. This set of interviews would be framed by goals similar to the previous set's: determining the relative weights of economic development and Hukou restrictions in destination cities in migrants' decision-making processes. As previously, I would expect to find that economic opportunities are destination cities' most compelling lures. Importantly, this set of interviews would illuminate perspectives from migrants currently grappling with NUP initiatives as they decide whether to move.

Over the course of these interviews, I would consider factors that might influence migrants' responses. As raised by Wang & Maino, migrants generally prefer destinations closer to their points of origin; more potential migrants are close to Dongguan in populous Guangdong than to Yingkou in less-crowded Liaoning. Even if their economies were comparable, it would seem natural, therefore, for Dongguan to attract more migrants. Moreover, differences in marketing and publicity about NUP policy changes might influence migrants' awareness of Hukou incentives and disincentives in prospective destination cities, confounding attempts to gauge the allure of different incentives.

Conclusions from my interview process would clarify whether economic factors uncovered in my quantitative investigation drive migrant decisions or coincide with them. If migrants were consistently driven to move to cities based upon perceived economic opportunities, I would conclude that NUP Hukou reform has little chance of changing urbanization patterns. If NUP policies were factored into decision-making processes, I would conclude that extraneous variables have tempered those policies' effects on potential migrants to Dongguan and Yingkou.

Having improved understanding of NUP policies intended to grow smaller cities, I would seek insight on complementary elements of the plan that lay beyond the scope of this paper. I would initiate a study of migration in megacities attempting to restrict further urbanization. Shenzhen and Shanghai, facing population pressures, have sought to limit additional migration. That said, they are among China's most productive economies. Conceivably, they have had just as much trouble limiting migration as Yingkou has had attracting migrants.

While there is more research to be done, my preliminary analysis reveals important trends. The Chinese Government launched NUP under the assumption that access to Hukou registration could be leveraged to incentivize migrants entering urban areas. Based on this assumption, it called for coordinated Hukou reform aimed at directing migrants towards smaller cities with what they saw as untapped growth potential. Migrants have not moved consistently with policymakers' expectations, continuing to enter cities notwithstanding their relatively stringent Hukou registration requirements.

This trend suggests that migrants make migration choices based on perceived economic advantages in potential destination cities. Market-driven urbanization sees migrants generally choose large, productive cities as their destinations rather than smaller, underdeveloped cities. China's state-managed solution to urbanization seems unable to combat this pattern. In 2014, Dongguan was larger and more productive than Yingkou; under NUP, the gulf between them has increased.

The policy implications of my findings are significant. NUP depends on the potential for existing Hukou and welfare policy tools to incentivize migration. If these tools are uncompelling to migrants, an entirely different approach may be needed. If economic development drives urbanization patterns, economic programs such as the Belt and Road Initiative may be better suited to shaping urbanization in the long run than NUP ever could be. Further investigations outlined above could refine my conclusions. The best state-managed solution to urbanization may involve leveraging markets, rather than manipulating people.

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Field Theory and Quantum Fluctuations of Fluid Membranes

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We review effective field theories of fluid membranes, including the role of topology, and outline two kinds of phase transitions due to quantum fluctuations. We second-quantize the quantum fluctuations of idealized fluid membranes at low temperature. We illustrate how to find the spectrum of fluctuations for the simple examples of a sphere and a torus by introducing isothermal coordinates.

Introduction

Cell membranes are made of amphiphilic lipid molecules — molecules which have both hydrophilic and hydrophobic parts. These lipids form a certain self-assembled structure which is thermodynamically stable; for example, many cells in humans are made of a lipid *bilayer*, which is mobile and deformable. In the limit that the variations in shape of the cell membrane are much larger than the size of the lipids themselves, we may coarse-grain the cell membrane and treat it as a smooth surface, or 2-manifold. This invites the use of geometry and topology to attack physical problems. On the basis of symmetry and invariance arguments, we first construct the continuum field theory describing the 2- manifold, which was first obtained by Helfrich [1]. In particular, a 2-manifold is of the same dimension as the world-sheet swept out by a string, and the continuum model of membrane energy was first derived in the con- text of string theory by Polyakov [2].

Mathematically, any surface embedded in a higher- dimensional space can move in the directions orthogonal to the surface; physically, these are vibrations. A "quantum" unit of vibration is termed a *quantum fluctuation*, and a change in the occupation number of vibrations is termed a *thermal fluctuation*. In any physical system, thermal fluctuations vanish at low temperatures, and studying the vibrational properties of a system is reduced to studying the quantum fluctuations — their wavelength, energy, and physical shape in space.

Although real cell membranes would freeze long before quantum fluctuations become important, this paper is concerned with *quantum*, rather than thermal, fluctuations. This is relevant to membranes which do not freeze at low temperatures; for example, the membranes between different phases of superfluid Helium [3]. Recently, there has been experimental interest in separating gaseous phases with superconducting membranes, which must also be kept at low temperatures. Studying the quantum fluctuations of these membranes is important because disturbances in the membrane position decrease the ease with which gaseous molecules can pass through the pores [4–6].

In this paper, we review the implications of Helfrich theory on two different kinds of phase transitions for low temperatures, driven by quantum fluctuations [7, 8], and also the appearance of topological quantities in the partition function of a quadratic Hamiltonian on a curved membrane [9]. Finally, following the canonical quantization of a string [10], we second-quantize the quantum fluctuations of a membrane for a quadratic Hamiltonian. In simple geometries, we can both obtain the energy spectrum and visualize what these fluctuations look like by introducing isothermal coordinates [11].

Notation and Mathematical Results

Consider a membrane (2-manifold) in d-dimensional space, and let $\vec{X} \in \mathbb{R}^d$ describe points in this d-space. The surface is 2-dimensional, so we use $\vec{\sigma} = (\sigma^1, \sigma^2)$ as local coordinates on the manifold. The *metric tensor*

$$g_{ij}(\vec{\sigma}) := \frac{\partial \vec{X}}{\partial \sigma^i} \frac{\partial \vec{X}}{\partial \sigma^j}$$

gives the Euclidean distance between two points on the functution $\vec{X}(\vec{\sigma})$

The area form is $d^2A = \sqrt{g} d\sigma^i \wedge d\sigma^j = \sqrt{g} d\sigma^i d\sigma^j$, where $g = \det g_{ij}$

Let $R_{1,2}$ be the principal radii of curvature, which can be locally defined, for example, via the *extrinsic curvature tensor* $\vec{K}_{ij}$ [11]. The *Gaussian curvature K* and the *mean curvature H* are defined in $d = 3$ as

$$K = \frac{1}{R_1 R_2} \text{ and } H = \frac{1}{2}(R_1^{-1} + R_2^{-1}).$$

A useful formula for H, which we will use later, is

$$H = \frac{1}{2} g^{ij} \vec{K}_{ij}, \text{ where } \vec{K}_{i\vec{K}} = \vec{\partial}_i D_j \vec{X}.$$

For, $d = 3$ there is only one direction for ,so is in fact a scalar.

Besides these definitions, we will also use a few theorems from differential geometry. Gauss' *theorem egregium* says that the Gaussian extrinsic curvature *K* is related to the Ricci curvature *R*,

$$2K = R.$$

The *Gauss-Bonnet theorem* says that, for a closed manifold without boundary (such as most cells),

$$\int d^2A \sqrt{g} R = 4\pi\chi = 8\pi(1-g),$$

where χ is the Euler characteristic, g is the genus, and *R* is the Ricci curvature.

The *Laplace-Beltrami operator* for functions on a manifold is defined to preserve an "integration by parts" for a scalar function f:

$$-\langle \text{div } X, f \rangle = \langle X, \nabla f \rangle,$$

where ∇ is is the covariant derivative. The explicit form is

$$\Delta f = \frac{1}{\sqrt{g}}\partial_i(g^{ij}\sqrt{g}\partial_j f).$$

In practice, this means that integration by parts, for example on a scalar field ϕ, looks like

$$\int d^2\sigma(\nabla\phi)^2 = -\int d^2\sigma\phi\Delta\phi.$$

Effective Field Theory of Fluid Membranes

These effective theories of fluid membranes assume that the characteristic time for in-plane deformations is much less than the time it takes for the membrane shape itself to change, so effectively, the energy can be described only in terms of the membrane shape. This resembles the Born-Oppenheimer approximation of quan- tum chemistry, where we care only about the positions of the atomic nuclei and not about the electrons themselves.

Construction of Helfrich energy

The **Helfrich energy**, which was derived on phenomenological considerations by Helfrich [1], is

$$\mathcal{H} = \int d^2A(\frac{\kappa}{2}H(\vec{\sigma})^2 + \bar{\kappa}K(\vec{\sigma})).$$

We can construct this by arguing that $\mathcal{H}$ must be only a function of $\vec{X}(\vec{\sigma})$ and that it must be translationally and rotationally invariant, and reparametrization invariant. We keep only those terms which are relevant in the IR. In other words,

- Rotational and translational invariance: $\mathcal{H}$ must be invariant under $X' = \mathcal{R}X + a$ and $g' = g$, where $\mathcal{R}$ is a rotation matrix.
- Diffeomorphic (reparametrization) invariance: $\mathcal{H}$ must be invariant under $X' = X$ and $g'_{ij}\frac{\partial\sigma'^i}{\partial\sigma^k}\frac{\partial\sigma'^j}{\partial\sigma^l} = g_{kl}$, or new coordinates σ' and old coordinates σ.
- Weyl (conformal) invariance: $\mathcal{H}$ must be invariant under $X' = X$, $g' = e^{\phi(\sigma)}g$.

Polchinski [10] shows that for a manifold without boundary,

$$\int_M d^2\sigma\sqrt{g}R,$$

where R is the scalar curvature (or Ricci scalar), is invariant under all three operations above. Under a Weyl rescaling,

$$\sqrt{g'}R' = \sqrt{g}(R - 2\Delta\phi),$$

and $\sqrt{g}\nabla_i v^i = \partial_i(-\sqrt{g}v^i)$ for any vector i, so the integral of the variation vanishes for a manifold without boundary.

As in Homework 1, Problem 4 of this course [12], the derivatives which are invariant under translations and rotations are

$$\partial_i\vec{X}_j \cdot \partial_i\vec{X}_j \text{ and } \partial_{ii}\vec{X}_j \cdot \partial_{kk}\vec{X}_j,$$

which, when generalized to manifolds M with curvature and integrated over the surface , give the contributions (up to multiplicative constants)

$$\int dA \text{ and } \int dA(\Delta\vec{X})^2,$$

and we do not care about higher derivatives because they will be irrelevant in the IR. Putting these three terms together gives the general Hamiltonian

$$\mathcal{H} = r_0\int d^2\sigma\sqrt{g} + \frac{\kappa_0}{2}\int d^2\sigma\sqrt{g}(\Delta\vec{X})^2 + \frac{\bar{\kappa}_0}{2}\int d^2\sigma\sqrt{g}R.$$

The $(\Delta\vec{X})$ term can be interpreted as $(\frac{1}{2}g^{ij}D_iD_j\vec{X})$, which is merely the mean curvature, H. Thus, this term returns the H^2 term in the Helfrich energy. The $\int d^2\sigma\sqrt{g}R$ term returns the other term in the Helfrich energy via Gauss' *theorem egregium*, R=2K

Here, r_0 is interpreted by the **Surface Tension** which turns out to be relevant, and $\kappa_0, \bar{\kappa}_0$ as the bending rigidity and the Gaussian rigidity, respectively, which both turn out to be marginal. You can guess this behavior by rescaling $\vec{X} \to \lambda\vec{X} \iff q \to \lambda^{-1}q$ where $\lambda > 1$: $r_0 \to \lambda^2 r_0$ and the curvature parameters are unchanged Because of the Gauss-Bonnet theorem, the $\int dAR$ contribution can be ignored unless the Euler characteristic of the manifold changes.

In fact, Helfrich introduced a spontaneous curvature H_0 to describe the shape of certain membranes,like those of red blood cells. The energy is modfied to

$$\mathcal{H} = \int d^2A(\frac{\kappa}{2}(H(\vec{\sigma}) - H_0)^2 + \bar{\kappa}$$

Variation $H(\vec{\sigma})$ of this energy returns the *shape equation* for mean curvature Tuning the numerical parameters can produce a solution of the shape equation which resembles the collapsed-sphere shape of a red blood cell [1, 13]. This is a mean-eld theory; because I am focusing on fluctuations, I will not describe it here.

Phase transitions due to quantum fluctuations

In this section, we review two kinds of crumpling transitions, both of which are due to quantum fluctuations. The first is a transition with respect to *temperature*: there exists a critical temperature T_c such that the membrane is flat for $T<T_c$ and crumpled for $T>T_c$ [7]. The $\hbar$: second is a transition with $\hbar^*$ respect to the size of Planck's $\hbar < \hbar^*$ constant, there exists a critical value such that the membrane is flat for and crumpled for $\hbar < \hbar^*$ [8]. Although it is not physically relevant, it is interesting because such a phase transition, being a true quantum phase transition, can occur even at T=0

Both treatments make use of the *Monge representation*, in which the two-dimensional coordinates $\vec{\sigma} = (\sigma_1, \sigma_2)$ are located on a flat plane lying underneath the membrane, rather than being local coordinates on the membrane itself. The position in $d = 3$ of a point on a two-dimensional membrane now described as

$$\vec{X}(\vec{\sigma}, t) = (\vec{\sigma}, f(\vec{\sigma}, t)).$$

Assuming only continuous deformations, we may ignore the topological term $\int d^2\sigma\sqrt{g}R$ in the Helfrich energy, add a kinetic term, and start with

$$\mathcal{H} = \int d^2\sigma\sqrt{g}(r + \frac{\lambda}{2}(\partial_t\vec{X})^2 + \frac{2}{\lambda}H^2).$$

The relation between coecient on the kinetic term and H term have been chosen for convenience. The quantum action $\frac{S}{\hbar}$ is expanded to the fourth order in the "height" variable f as

$$\frac{1}{\hbar}\int_{t,\vec{\sigma}}\left(\frac{\lambda}{2}(\partial_t f)^2+\frac{r}{2}(\partial_i f)^2+\frac{1}{2\lambda}(\partial^2 f)^2-\frac{\lambda}{4}(\partial_t f)^2(\partial_i f)^2-\frac{r}{8}(\partial_i f)^2(\partial_j f)^2-\frac{1}{4\lambda}(\partial_i f)^2(\partial^2 f)^2-\frac{1}{\lambda}(\partial_i f\partial_j f)(\partial_i\partial_j f)(\partial^2 f)\right)$$

The crumpling transition is equivalent to asking the question: does the rigidity λ flow to 0 or ∞ in the IR? If $\lambda \to 0$, $\frac{1}{\lambda} \to \infty$, so the membrane is "stiff" and hence flat. If $\lambda \to \infty$, the membrane is "floppy" and hence crumpled.

Crumpling at high temperature:

We use the $\mathcal{O}(f^4)$ terms to renormalize the parameters in the quadratic part of the energy,

$$\frac{S_0}{\hbar}=\int dtd^2\sigma\left(\frac{\lambda}{2\hbar}(\partial_t f)^2+\frac{r}{2\hbar}(\partial_i f)^2+\frac{1}{2\hbar\lambda}(\partial^2 f)^2\right).$$

As outlined in Borelli [7], the result of Wilsonian perturbation theory is the flow equation

$$\beta(\lambda)=\mu\partial_\mu\lambda=(1-d-\frac{3u_{\text{qm}}-4u_{\text{th}}}{16\pi})\lambda.$$

$u_{\text{qm}} = \hbar r_0\lambda_0, u_{\text{th}} = kT\lambda_0$ are suitably chosen expansion parameters in terms of the unrenormalized operators r_0, λ_0. There is a corresponding flow equation for *r*. The main takeaway is that there exists a nontrivial fixed point

$$(r=0,\lambda=\lambda^*(T))$$

such that the flow of λ away from this fixed point changes direction at $T = T^*$. For $T < T^*$, λ flows to 0; for $T > T^*$, λ flows to ∞ This can be interpreted as a competition between the expansion parameters u_{qm} and u_{th}. When thermal fluctuations are large enough (i.e. for large enough T), the effect of u_{th}. (thermal fluctuations) overpowers that of u_{qm} (quantum fluctuations).

Crumpling at high $\hbar$: What if we allow to $\hbar$ change?

As outlined in Foltin [8], the flow equation for λ

$$\beta(\lambda)=-\frac{\beta(\hbar)}{\epsilon}\lambda,$$

where $\beta(\hbar)=\hbar(d-\hbar)$. This means that as $\mu\to 0 \implies \lambda \to 0$ for $\hbar < \hbar^* = d$, and $\mu \to 0 \implies \lambda \to \infty$ for $\hbar > \hbar^* = d$. There is thus a crumpling transition at $\hbar = \hbar^* = d$. The membrane is flat for $\hbar < \hbar^*$ and crumpled for $\hbar > \hbar^*$.

Free field on a surface

Our aim here is to compute the most divergent terms in the partition function *Z* of a massless eld on a curved surface. We will take the leading (quadratic) terms from the $\mathcal{O}(f^4)$ expansion of the Helfrich energy in the previous subsection, to avoiding performing perturbation theory but still return interesting mathematical results. The result is that the coecients of the partition function turn out to be related to the topological properties of the surface [9].

Go back to the parametrization where $\vec{\sigma}=(\sigma_1,\sigma_2)$ are local coordinates of points on the surface, rather than Monge coordinates. Consider a massless free field $\phi(\sigma)$ on a 2-manifold with action

$$S=\frac{1}{2}\int_M d^2\sigma\sqrt{g}g^{ij}(\partial_i\phi)(\partial_j\phi).$$

If M has no boundary, then

$$S=\frac{1}{2}\int_M d^2\sigma\sqrt{g}\phi(-\Delta)\phi$$

$$\implies Z=\int D\phi e^{-S[\phi]}\sim\frac{1}{\sqrt{\det(-\Delta)}}.$$

However, defining the measure $D\phi$ is nontrivial; we require it to be reparameterization invariant. The simplest way to do so is to write

$$\phi=\sum_{k=0}^{\infty}a_k\phi_k,$$

where

$$\Delta\phi_k=-\lambda_k\phi_k,\langle\phi_k|\phi_l\rangle=\int_M d^2\sigma\sqrt{g}\phi_k\phi_l=\delta_{kl}.$$

We see that *k* is like a momentum and 0 is like an energy. Then

$$D\phi=\prod_k da_k \text{ and } \det(-\Delta)=e^{\sum_k\ln\lambda_k}.$$

There are two issues that arise

1. $\lambda_0 = 0$: This makes the determinant equal to zero. We will just ignore $k = 0$ the mode; this is equivalent to assuming that the manifold (i.e. red blood cell) has a finite size.
2. As $k \to \infty$, $\lambda_k \sim k^2$ gives a divergent contribution. We will introduce a UV cuto in a reparameterization-invariant way. (However, the divergent contributions might still have regulatordependence.) Because

$$\det(-\nabla^2)\sim e^{\sum_k\ln\lambda_k}\sim e^{\Lambda^2},$$

we expect

$$\ln Z=B\Lambda^2+C\ln(\Lambda^2)+D+\mathcal{O}(\Lambda^{-2}).$$

We will compute these coecients in terms of the geometry of the surface.

Heat-kernel regularization:

Let a prime, ', omit the $k = 0$ This method will utilize the Green function of the Laplace, or heat, equation. Let $\epsilon=\frac{1}{\Lambda^2}$ be a cutoff and note that

$$\log\det{}'(-\Delta\epsilon)=\text{tr}'[\log(-\Delta\epsilon)]$$

$$=-\text{tr}'[\int_\epsilon^\infty\frac{dt}{t}e^{t\Delta}]=-\int_\epsilon^\infty\frac{dt}{t}\text{tr}'(e^{t\Delta}).$$

This follows by noting that

$$-\int_\epsilon^\infty\frac{dt}{t}e^{-\lambda_k t}=-\int_{\lambda_k\epsilon}^\infty\frac{du}{u}e^{-u}\sim\log(\lambda_k\Delta),$$

at least when is small, so $e^{-u}\approx 1$.

Now, we use the fact that

$$\text{tr}'(e^{t\Delta})=(\int_M dAG(\sigma',\sigma;t))-1.$$

Note that $\mathrm{tr}'(e^{t\Delta})$ clearly decreases with time. Here, $G(\sigma,\sigma';t)$ is the solution to the differential equation $\partial_t G = \nabla_\sigma^2 G$ with initial condition $G(\sigma,\sigma';t=0)=\frac{\delta^{(2)}(\sigma-\sigma')}{\sqrt{g}}$.

This follows by assuming the general form

$$G(\sigma',\sigma;t)=\sum_{k=0}^{\infty} a_k\phi_k(\sigma)e^{-\lambda_k}$$

and matching to the intical conditions. We find $a_k = \phi_k(\sigma')$ and therefore

$$G(\sigma',\sigma;t)=\sum_{k=0}^{\infty}\phi_k(\sigma')\phi_k(\sigma)e^{-\lambda_k t}$$

$$\approx\sum_{k=0}^{\infty}\phi_k(\sigma)\phi_k(\sigma)e^{-\lambda_k t},$$

if we assume that $\phi(\sigma')\approx\phi(\sigma)$, this gives

$$\mathrm{tr}'(e^{t\Delta})=\int_M d^2\sigma\sqrt{g}G(\sigma',\sigma;t).$$

This is a reasonable approximation to make when is ϵ the important parameter and is very small. Because the divergence is for small $t\to\epsilon$, values of t mean that the diffusive wave has not spread out very much, which means $\sigma'\approx\sigma$ is a fine approximationb to make.

For short times,

$$G(\sigma,\sigma';t)\approx\frac{1}{4\pi}(\frac{1}{t}+\frac{R(\sigma)}{6}+\mathcal{O}(t)),$$

where R is the Ricci curvature at point σ [9]. This, of course, looks a bit like the solution to the diusion equation, $\sim e^{-x^2/t}$. Immediately (putting back $\epsilon=\Lambda^{-2}$) integration over t gives

$$\ln Z=\frac{-\Lambda^2}{4\pi}\int_M d^2\sigma\sqrt{g}+\frac{\log\Lambda^2}{24\pi}\int_M d^2\sigma\sqrt{g}R+\mathcal{O}(1).$$

Conclusion:

$B\propto$ surface area, $C\propto$ Euler characteristic χ.

Second Quantization of Oscillations of a Closed 2 Manifold

It is possible to use the formalism developed above and second-quantize the quantum fluctuations of a fluid membrane, following Polchinski's quantization for open strings [10]. Although this is irrelevant for biological membranes, because they would freeze long before temperatures became low enough for quantum fluctuations to be relevant, this treatment is relevant for nonbiological membranes, such as the interfaces between dierent phases in super fluid helium; for example, see Marchenkov et. al [3]. Assume we have a 2-manifold parametrized by atlas coordinates (s_1,s_2) which lives in 3-space, described by $\vec{X}=(X_1,X_2,X_3)$. Because 3−2 = 1, locally there is only one direction orthogonal to the surface of the manifold. The small displacement of the membrane can be treated as orthogonal to its surface,

$$\delta\vec{X}\perp\hat{s}_1,\hat{s}_2,$$

so we can simply treat this displacement $\delta\vec{X}$ as a scalar field ϕ (i.e. because it is one-dimensional). Hence, the machinery developed in the previous section is still applicable.

Because I do not expect there to be a gap in the spectrum, I will not add a mass term to the action. I will however, add a kinetic term:

$$S=\int d\tau d^2s\sqrt{g(s)}(g^{ij}\partial_i\phi\partial_j\phi-(\partial_\tau\phi)^2).$$

As in the previous section, the equation of motion can be derived by variation of the action with respect to ϕ and integration by parts. The result is

$$(\Delta-\partial_\tau^2)\phi(s)=0,$$

where Δ is the Laplace-Beltrami operator. This gives an approximate behavior

$$\phi_k(\tau)\sim e^{\pm\lambda_k\tau}$$

for the kth oscillatory mode. The eigenfunction is described by the eigenvalue The λ_k.general timedependent solution for the position of a particular point on the membrane is

$$\vec{X}(\vec{s},\tau)=\vec{X}(\vec{s},0)+\vec{v}\tau+(\hat{s}_1\times\hat{s}_2)\sum_{k=-\infty}^{\infty}\alpha_k\phi_k(\vec{s},\tau).$$

a

In the above, $\vec{X}(\vec{s},0)$ is the starting point (in 3-space) of the point on the membrane with atlas coordinates $\vec{s}$, $\vec{v}$ is an overall drift velocity of the entire membrane, $\hat{s}_1\times\hat{s}_2$ is the fluctuation direction (locally orthogonal to the surface), and the sum runs over all fluctuations. I implicitly assumed the membrane was originally in a nondegenerate ground state, so there are no trends in the overall shape, other than fluctuations.

An individual quantum mode is described by $\phi_k(\vec{s},\tau)$, with appropriate normalization and boundary conditions. In real-time, the eigenfunctions go as $e^{-i\omega t}$, so we have

$$\frac{1}{T}\int_0^T dte^{-i(\lambda_k+\lambda_l)t}=\delta_{k,-l},$$

$$\int d^2s\sqrt{g}\phi_k(\vec{s})\phi_l(\vec{s})=\delta_{k,\pm l}.$$

We would like to introduce creation and annihilation operators. This is possible by introducing canonical commutators,

$$[\phi(\vec{s},t),\pi(\vec{s}',t')]=i\delta(\vec{s}-\vec{s}')\delta(t-t'),$$

where $\pi(\vec{s},t)=\partial_t\phi(\vec{s},t)$ is the canonically conjugate momentum. Introduce the real-time conventions

$$\phi(\vec{s},t)=\sum_{k=-\infty,k\neq0}^{\infty}\frac{\alpha_k}{\sqrt{\lambda_k}}\phi_k(\vec{s})e^{-i\lambda_k t},$$

$$\pi(\vec{s},t)=\sum_{l=-\infty,l\neq0}^{\infty}-i\alpha_l\sqrt{\lambda_l}\phi_l(\vec{s})e^{-i\lambda_l t}.$$

Because $\phi,\pi\in\mathbb{R}$, $\lambda_{-k}=-\lambda_k$, $\alpha_{-k}=\alpha_k^*$, and $\phi_{-k}(\vec{s})=\phi_k(\vec{s})$. Above, $\sqrt{\lambda_k}$ is allowed to be imaginary. We find that

$$[\phi(\vec{s},t),\pi(\vec{s}',t')]=i\sum_{kl}[\alpha_k,\alpha_l]\phi_k(\vec{s})\phi_l(\vec{s}')e^{-i(\lambda_k+\lambda_l)t}.$$

Integrating over $\int d^2s$ and $\frac{1}{T}\int dt$ and using the normalizations above gives the commutations

$$[\alpha_k,\alpha_l]=\delta_{k,-l}.$$

If we constrain $k\geq0$ and write $\alpha_{-k}=\alpha_k^\dagger$, we have

$$[\alpha_k,\alpha_l^\dagger]=\delta_{k,l}$$

which is the usual commutation. Essentially, the scalar relation $\alpha_{-k} = \alpha_k^*$ is promoted to the operator relation $\alpha_{-k} = \alpha_k^\dagger$. Hence we can write the spectrum in terms of a "ladder" of vibrational occupations, for each positive energy state λ_k. The general excited state $|\Psi\rangle$ can be written

$$|\Psi\rangle = \prod_{k=1}^{\infty} \frac{(\alpha_k^\dagger)^{n_k}}{\sqrt{n_k!}}|0\rangle.$$

If the membrane lives in $d > 3$ dimensions and we diagonalize the oscillations into uncoupled directions $3 \leq i \leq d$, the general excited state is

$$|\Psi\rangle = \prod_{i=3}^{d}\prod_{k_i=1}^{\infty} \frac{(\alpha_{k_i}^\dagger)^{n_{k_i}}}{\sqrt{n_{k_i}!}}|0\rangle.$$

Spectrum Via Conformal Coordinates

We saw above that we can interpret the quantum fluctuations of a fluid membrane as a collection of bosonic phonon modes, each with a dierent energy. The occupation of these modes is governed by the Bose-Einstein distribution, so determining the spectrum can yield, for example, the energy $E(T)$ and hence specic heat $C(T)$ of the fluid membrane. The main issue with the above quantization is the diculty of diagonalizing the Laplace-Beltrami operator, Δ. Unlike in at space, the Laplace operator is generally not diagonal in the dierent components, essentially because the metric is no longer diagonal.

There are several ways to solve this. One method is to use computational programs, such as [14]. For simple surfaces, we can diagonalize Δ the metric and hence also diagonalize through the technique of introducing *conformal coordinates or isothermal coordinates*, which have induced metric [11]

$$ds^2 = g(u,v)(du^2 + dv^2).$$

The Laplace operator takes a very simple form,

$$\Delta = \partial_u^2 + \partial_v^2.$$

It can be proved that such a diagonalization always exists,though it can be found analytically only for simple cases. Let us consider two examples.

Sphere

The conformal coordinates of a sphere of radius R can be found by stereographic projection onto xy-the plane. The result is

$$ds^2 = \frac{4R^2}{(R^2 + x^2 + y^2)}(dx^2 + dy^2).$$

The xy-plane in question extends to infinity, $-\infty \leq x, y \leq \infty$, so we switch to (r,θ) polar coordinates. According to Kuttler [15], the eigenfunctions and eigenvalues of the Laplace operator for a circular membrane are

$$u_{mn} = \mathcal{J}_m(\frac{j_{mn}r}{a})(A\cos(m\theta) + B\sin(m\theta)),$$

$$\lambda_{mn} = (\frac{j_{mn}}{a})^2, m \in \mathbb{Z}^0, n \in \mathbb{Z}^+,$$

where j_{mn} is the nth zero of the mth Bessel function. In this stereographic projection, the eigenfunction $\phi_k(\vec{s})$should be single-valued at $r \to \infty$. Because the Bessel function tends to zero, $J_m(x) \to 0$ as $x \to \infty$, this is guaranteed anyway. So, the above roots j_{mn} give the correct spectrum. Although $u_{mn} \to 0$ for $r \to \infty$, it is not necessarily true that $\phi_k(\vec{s}) \to 0$as $r \to \infty$. This is because we can add a solution $\eta$of the homogeneous equation $\Delta\eta(\vec{s}) = 0$ to $\phi_k(\vec{s})$ and preserve the eigenvalue.

Torus

The conformal coordinates of a torus, originally described by $(\sqrt{x^2+y^2} - R_1)^2 + z^2 = R_2^2$, can be expressed in the dimensionless "aspect ratio" $r := \frac{R_1}{R_2}$ as[16]

$$ds^2 = R_2^2(\frac{r^2-1}{r-\cos\phi})^2(d\theta^2 + \frac{d\phi^2}{r^2-1}) = g(\theta,\tilde{\phi})(d\theta^2 + d\tilde{\phi}^2).$$

Here,$\theta$is the usual polar angle in two-dimensional (r,θ)coordinates. $\tilde{\phi} = (r^2-1)^{-1/2}\phi$,and ϕ is expressed in terms of α, which decribes vertical position (for example,$z = R_2\sin\alpha$in the Cartesian representation).

$$\cos\alpha = \frac{r\cos\phi - 1}{r - \cos\phi}.$$

Because$0 \leq \theta, \phi \leq 2\pi$, the torus is conformally equivalent to a rectangle. This is aesthetically pleasing because we know that we can fold up a rectangle to make a torus, by rst making a cylinder and then connecting the ends of the cylinder. The eigenfunctions and eigenvalues of the Laplace equation for a rectangular region are [15]

$$u_{mn}(\theta,\tilde{\phi}) = \sin(\frac{m\pi\theta}{a})\sin(\frac{n\pi\tilde{\phi}}{b}),$$

$$\lambda_{mn} = \pi^2((\frac{m}{a})^2 + (\frac{n}{b})^2).$$

Here, $m, n \in \mathbb{Z}^+$, $a = 2\pi, b = \frac{2\pi}{\sqrt{r^2-1}}$

Computation of physical quantities

For agreement with the eigenvalues λ_{mn} above, let us label eigenmodes with (mn) instead of with$k$.The average number of phonons in a given mode is given by the Bose-Einstein distribution,

$$\langle N_{mn}\rangle = \frac{1}{e^{\beta(\lambda_{mn}-\mu)} - 1}.$$

The partition function is merely

$$Z = \prod_{mn}\left(\sum_{N_{mn}=0}^{\infty} e^{-\beta N_{mn}\lambda_{mn}}\right) = \prod_{mn}\frac{1}{1-e^{-\beta\lambda_{mn}}}.$$

and the energy and specic heat $E(T)$, $C(T)$ follows from differentiating with respect to $\beta = \frac{1}{kT}$. Thus, if we are interested only in the thermal behavior of a membrane, the second quantization gives a much simpler partition function than the typical partition function of field theory, $Z = \int \mathcal{D}\phi e^{-\beta\mathcal{H}[\phi]}$.

Conclusion

In this paper, we derived the coarsed-grained (Helfrich) model of a fluid membrane via invariance arguments and studied its quantum fluctuations. In particular, we found a crumpling transition temperature T^*at which thermal fluctuations overpower quantum fluctuations, and a critical value $\hbar^*$at which there is a crumpling

transition even at $T = 0$. We found that topological quantities (surface area, Euler characteristic) appear in the computation of the divergent parts of the free energy, lnZ. Finally, we studied individual quantum phonon modes by introducing creation and annihilation operators. Conformal coordinates help us visualize what these vibrational modes look like.

For the thermally-induced crumpling transition, it would be interesting to extend our results to account for boundary effects, because the systems for which this calculation is relevant, such as super fluid Helium or the superconducting membranes, are manifolds with boundaries. For the quantization of thermal fluctuations, it would be interesting to try to build a quantum field theory out of fields such as

$$\phi(\vec{\sigma}, t) = \sum_k \alpha_k \phi_k(\vec{s}) e^{-i\lambda_k t} + \alpha_k^\dagger \phi_k(\vec{s}) e^{i\lambda_k t}$$

and construct a Lagrangian out of these fields, which are now operators. This mirrors the procedure in relativisticfield theory. It is conceivable that such a quantum field theory, which unlike Helfrich theory accounts for quantum fluctuations, could be generalized to systems more general than fluid membranes. For example, the curvatures H and K could also have relevance in surface science, where nonzero curvature is interpreted as a change in coordination number of an atom on the surface. The Lagrangian would then be expanded in terms of the fields ϕ, and $\alpha_k^\dagger$ would be interpreted as creating a k-state phonon on the surface.

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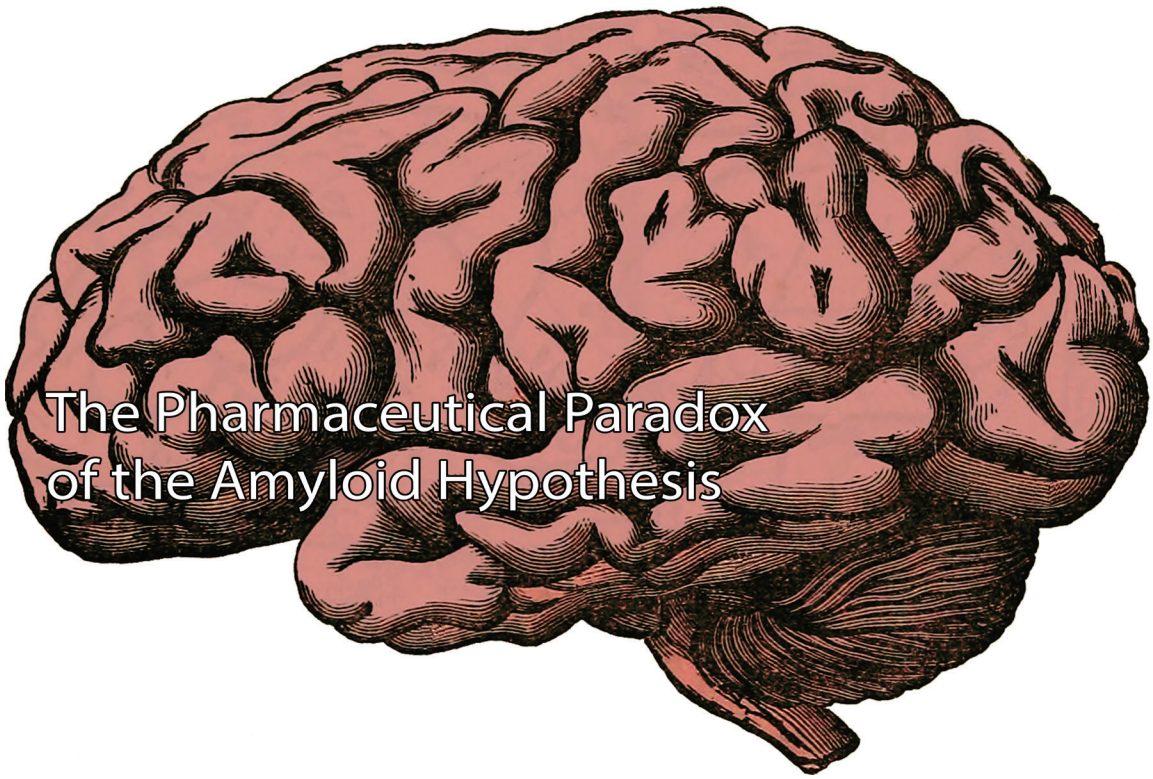
Features



The Pharmaceutical Paradox of the Amyloid Hypothesis

Brandon Gong '22

This past October marked the biggest pharmaceutical surprise of 2019. Biogen, after discontinuing Phase III clinical testing for its flagship anti-Alzheimer's drug candidate, aducanumab, has now submitted the same therapeutic for FDA approval based on results from a larger clinical dataset. This announcement was a huge reversal of fortune for the Cambridge-based pharmaceutical company, which saw its stock prices soar after experiencing a disappointing downfall earlier in the year, when it originally pronounced aducanumab as a failure.

"AD drug development has been littered with over a hundred pharmaceutical failures"

For the scientific community at large, this news represents a key milestone in the search for the first disease-modifying cure for Alzheimer's disease (AD). However, even in light of this exciting turn of events, it is important to remember that there is still much to be uncovered in the fight against AD. The twenty-year history of AD drug development has been littered with over a hundred pharmaceutical failures and no effective treatment for stopping the disease. Biogen's spring discontinuation of aducanumab had caused many researchers to step back and re-evaluate the direction of the AD field. Specifically, the validity of the foundational theory of AD research, the amyloid hypothesis, had been facing more scrutiny than ever before, and AD scientists were beginning to take new directions in their research. Now, aducanumab's resurrection leaves researchers at a crossroads regarding the long-standing amyloid hypothesis.

Background of AD and the amyloid hypothesis

AD is an irreversible, chronic progressive neurodegenerative disorder that destroys memory, learning, and other important mental functions. The public health issue that AD presents cannot be overstated. One in three will develop AD or another similar form of dementia over the course of their lifetimes. Furthermore, among the top ten leading causes of death in the United States, AD is the only one that cannot be prevented, cured, or slowed down (2016 Alzheimer's Disease Facts and Figures Report).

To date, the FDA has only approved of four unique medications for AD. However, these drugs merely aid in temporary symptomatic relief of AD, and do not affect the underlying disease pathology or prevent disease

progression (Mielke). As a result, an estimated 5.4 million Americans live with AD, costing the nation an estimated $236 billion in healthcare costs. Due to the lack of effective disease-modifying therapeutics on the market, this population is only expected to continue to rise; by 2050, it is estimated that 14 million Americans will be afflicted with AD (2016 Alzheimer's Disease Facts and Figures Report).

"An estimated 5.4 million Americans live with AD"

For nearly thirty years, the central basis behind most AD research has been the amyloid hypothesis. This theory postulates that the accumulation of amyloid-beta (Aβ) protein deposits in the brain leads to the development of tau protein tangles, ultimately resulting in neuronal death, synaptic loss, and eventually, dementia (Selkoe and Hardy). This proposed mechanism is often referred to as the "amyloid cascade", as it is the formation of toxic Aβ deposits that triggers the overall disease pathology. These Aβ deposits are formed from the excessive aggregation of Aβ proteins, which are cleaved from amyloid precursor protein (APP) by two enzymes: β-secretase 1 (BACE1) and γ-secretase (O'Brien and Wong).

The prevalence of Aβ protein in the post-mortem brains of AD patients, along with ample evidence of Aβ neurotoxicity in cell and animal models, led researchers to support this theory. For example, mice that are genetically altered to overexpress Aβ develop rapid memory loss that is strongly reminiscent of AD symptoms in humans (Sasaguri). Moreover, mutations in genes that code for APP and presenilin 1, the active region of γ-secretase, have been critically linked to increased risk of developing early-onset AD (Tanzi and Bertram). Further clinical evidence stems from humans with Down's syndrome, who retain three copies of chromosome 21 – the chromosome that harbors the *APP* gene – and tend to experience the neuropathological symptoms of AD at higher rates than humans without this chromosomal abnormality (Wiseman). Summarily, due to the observed correlation between Aβ and AD, AD drug development has largely centered around the inhibition of Aβ production or the clearance of Aβ plaques from the brain.

Therapeutic development for AD

Yet, for all of the basic research findings that implicate amyloid in the progression of AD, there has been no success in translating these results into a cure – until recently. Dozens of amyloid-based therapeutics, ranging from BACE1 and γ-secretase inhibitors to reagents that are designed to specifically bind Aβ, have all failed in clinical drug trials, with varying reasons as to why. In the past, -secretase inhibitors were shown to interfere with critical cellular signaling pathways, resulting in debilitating side effects to patients (Xia). BACE1 inhibitors have been associated with steeper cognitive decline in treated subjects when compared to the control, untreated AD patients (Selkoe). Previous Aβ antibodies had also failed to retain positive results in clinical testing. Both crenezumab and solanezumab, which are monoclonal antibodies that target specific forms of Aβ peptides, were unable to ameliorate memory and mitigate cognitive decline in patients when compared to placebo (van Dyck). These failures, including aducanumab's previous discontinuation, led many researchers to question the role of amyloid in AD; some scientists have argued that amyloid is merely a byproduct of larger mechanistic damage in the brain, and therefore not a viable option to target for the alteration of disease progression.

Aducanumab's recent drug trial success now presents a refutation to detractors of the amyloid hypothesis. Although aducanumab is also a monoclonal Aβ antibody, there are several aspects that differentiate aducanumab

"some scientists have argued that amyloid is merely a byproduct of larger mechanistic damage"

from its failed predecessors. Aducanumab was developed through a process called "reverse translational medicine", in which operative antibodies from the immune systems of healthy, aged donors who had successfully resisted AD are screened for reactivity with Aβ (Sevigny). As such, aducanumab is able to bind Aβ aggregates, including forms of the protein are thought to be more toxic than previously targeted variants. Based on promising preclinical results, Biogen launched two Phase III clinical trials, EMERGE and ENGAGE, in late 2015.

In March 2019, a futility analysis rendered a negative result for aducanumab, predicting that these studies were unlikely to meet their primary endpoints upon completion. As a result, Biogen discontinued further testing for aducanumab, which was devastating blow for the AD community at large. However, this futility analysis was only based on data up until December 2018. After the discontinuation of these studies, additional data from

the trials – now up until March 2019 - became available. An analysis of this larger dataset revealed that in the EMERGE trial, treatment with the high-dose variant of aducanumab was able to significantly reduce cognitive decline when compared to placebo. This finding, along with preliminary meetings with the FDA, led Biogen to reverse its decision on aducanumab in October 2019.

Whether the FDA finds these new results compelling enough to approve aducanumab remains up in the air. It's important to note that data from EMERGE demonstrated that aducanumab significantly decreased cognitive decline compared to placebo; the results from ENGAGE did not support these findings outright. Nevertheless, the consequences of Biogen's resurrection of aducanumab remain something to look out for in the coming years. For decades, the amyloid hypothesis had reigned as the dominant theory of AD pathogenesis. Yet, in this time, no tangible therapeutic progress was realized, all while the population of AD patients increased exponentially. The cancellation of aducanumab back in March 2019 had heralded much change in how scientists are planning to approach future AD research. In the summer of 2019, AD research conferences stressed diversification in the field, with a special emphasis on the development of diagnostic AD biomarker tests. Even though aducanumab appears to have breathed new life into amyloid hypothesis, this news should not detract from the scientific pursuit of other methods for AD treatment. The AD community cannot risk keeping all of its eggs in the amyloid basket for any longer.

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Insert Title Here: Interview with Dr. Shiv Pillai

Catherine Gallori '22

Dr. Shiv Pillai is the Director of Harvard's PhD and MMSc programs in Immunology, the Director of MGH's NIH-funded Autoimmune Center of Excellence, a Professor of Medicine and Health Sciences and Technology at Harvard Medical School, and a Ragon Institute group leader. World-renowned for his work in B-cell immunology, Dr. Pillai is also a gifted teacher and has mentored countless students in his 30-odd years at Harvard. THURJ writer Catherine Gallori recently had the opporunity to meet with him to discuss his work.

CG: Thank you so much for giving us the opportunity to speak with you! Could you give us an overview of how you ended up researching immunology?

SP: When I was growing up in India, I read this book that my mom had given me, Microbe Hunters. It was about Koch and Pasteur— that era of biology when we suddenly understood something about disease. Then, when I was in high school, my mom went to the US on a Fulbright, and she brought me back a biology textbook. It was a fabulous book, filled with experiments and descriptions of the early days of genetics, and I read that too. And I was absolutely fascinated by all of it! So I thought I should go to medical school. At that time in India, if you were a smart kid you went to engineering school, and if you were bad at math, you went to medical school. I was good at math, but I was interested in this stuff. So, against the advice of my math teacher, I might add, I went to medical school with the intention of going into research.

"So, against the advice of my math teacher, I might add, I went to medical school with the intention of going into research"

CG: What discovery are you most proud of?

SP: You should never be too proud of anything. But I guess I am most proud of the contribution of mine that helped people the most. The most interesting thing I did as a postdoc, when I discovered the surrogate light chain of the Pre-B Cell Receptor. But then we discovered BTK signalling— that Bruton's Tyrosine Kinase is involved in signalling from the pre-BCR, which is required for B cell development. I wrote all of these grants on BTK for the NIH, where I said that the research could be useful

to study leukemia. But I never expected that today, BTK inhibitors would be *the* treatment for chronic lymphocytic leukemia, a B-cell cancer. So I know at least something we did came into great use there.

CG: What is your lab working on currently?

SP: We are doing 3 different things, broadly speaking. One project is trying to understand how you make a mature B-cell, so we need to understand DNA methylation, metabolism, and so on. A second, broader question is why does anyone get a disease? We understand genetic disease, we understand what happens in cancer, and we understand infectious disease, but everything else? We are studying two of these so-called 'common diseases', scleroderma and IgG4, in great depth. Scleroderma is a very bad disease— women diagnosed with it lose about 25 years of their lives— and we can't model it in mice, so we're using these new, high-tech tools to study the diseases in humans. The third area relates to single gene mutations that affect the immune system— it involves creating and studying cohorts of patients with single gene mutations, all of which are fascinating phenotypes that help us understand how the human immune system works. The whole goal is to understand something, and then start a clinical trial based on what you found. In one of our clinical trials the treatment was a blockbuster: it actually reversed the condition. So there is basic science, but disease as well.

"I think I am completely convinced that the root to understanding most diseases is to understand the immune system"

CG: What do you see as the most promising avenue for Immunology today?

SP: I think I am completely convinced that the root to understanding most diseases is to understand the immune system. Now, you can be born with a genetic disorder of the nervous system— that's different, but those are relatively rare. I think most other diseases— take schizophrenia, or possibly autism— are likely immune-based. There is very nice data on schizophrenia, showing how it's basically a defect in synaptic pruning, which is regulated by the complement system, a major component of immune response. In addition, autism may be related to maternal T helper cells causing problems in the fetus, though that's from an animal model. And if you want to really understand these diseases, today is the time to do it— we have these amazing molecular tools like CRISPR to go in great depth in humans, because we can't do these kinds of experiments in a mouse. For instance, some patients or ours had a specific mutation of a protein important for T-regulatory cell function, but it was hard to know if that was the real cause of their disease. One of our collaborators at UCSF has these tools where he edits the DNA of these T-regulatory cells with CRISPR. Now we can just take the patient's T-cells and fix the mutation, and see if they are normal or not. So, I think the molecular tools have become so good that we are really making progress now.

CG: You do a lot of teaching and mentoring: in addition to teaching medical students in the Harvard-MIT HST program, you run Harvard's PhD and Masters programs in Immunology, and teach undergrads at the College in MCB 169. Why do you love teaching so much?

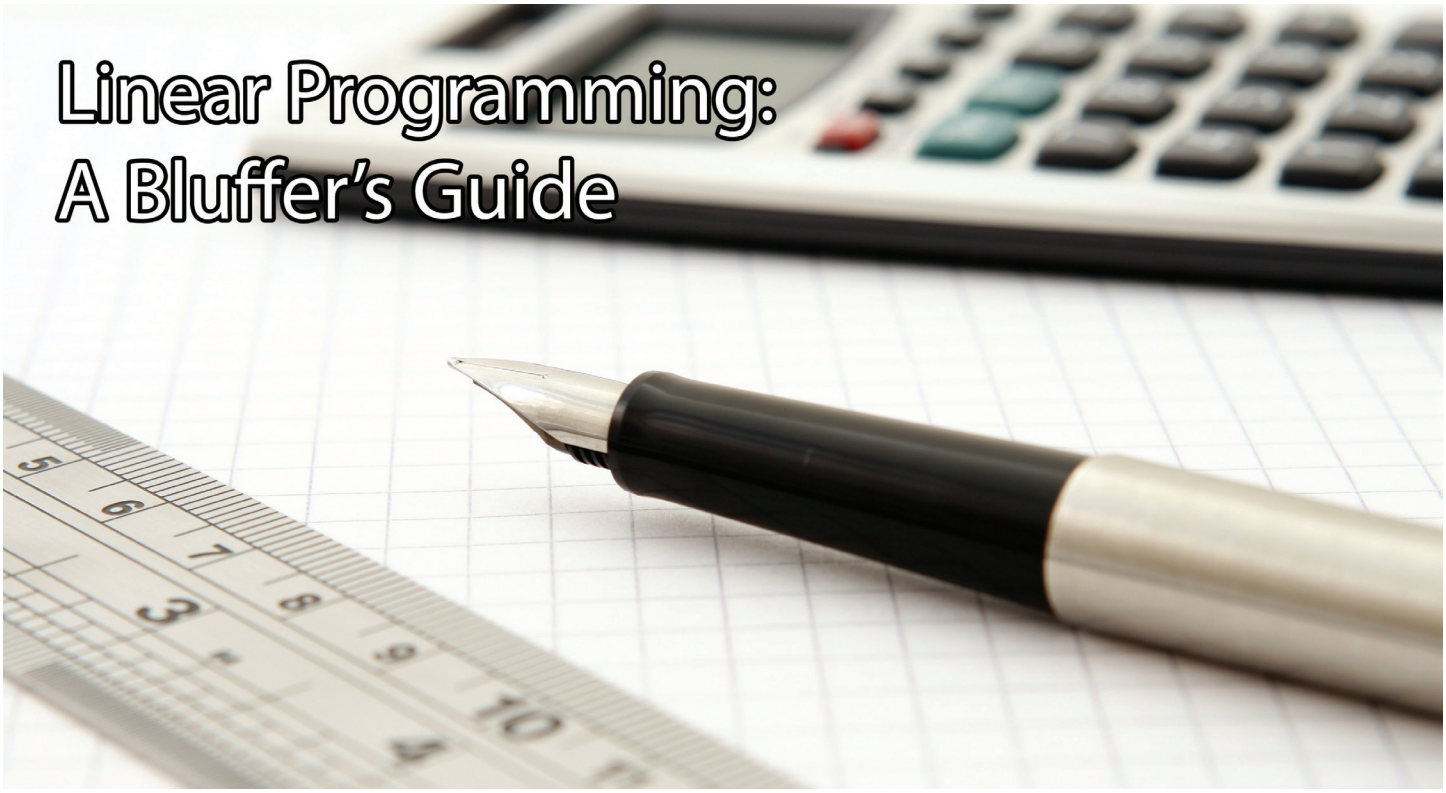
SP: I was a serious thespian at one time— I did everything from Pinter to Albee— so teaching for me became a natural outlet. Today, I am not going to take the time to learn lines and go on stage, but I can do something in front of a captive audience all the time. Like my rhymes: when I was a kid in medical school, I edited the college magazine and wrote rhymes. When I courted my wife I wrote rhymes for her too. But then I read this great poet, Miroslav Holub, who said "there is poetry in everything, that is the greatest argument against poetry," and I realized I didn't want to be this pretentious poet all my life. Then, in 2004 I started teaching MCB 169 for the first time, and I knew the students needed some entertainment. So one weekend, I wrote a rhyme— it was the lymphocyte rap— and performed it in class, and the students were highly entertained. Then, in 2007, my head TF said "the professor will have a rhyme at the end of every lecture"-- and I had just 4 rhymes for 20 lectures. But I did put a large number of rhymes together that year!

CG: As such an experienced mentor, what final words do you have for young scientists?

SP: I think the most important thing for any young person is to find out whether you really have a passion for science. There are two things to do. The first is to identify if you are curious enough. What does it matter

to me to know why this protein is in the nucleus, or why this protein affects that cell type? Unless you are curious enough, you will not be happy in science, no matter how brilliant you are. The second is that by actually doing science, you can figure out for yourself whether you want to do this. Science is difficult. It involves a lot of pain and suffering, and you need to balance that with the satisfaction you get from the process of discovery. You can't see that in a summer: you have to do your own science, not just follow the post-doc's directions. So you should spend at least a year in a lab. Frankly, some people do that only after starting a PhD and *then* they figure out I don't want to do this. So I think it's useful to discover those things about yourself early on. For me, there is something very satisfying in the objectivity of science. We are doing is something that is more permanent: I know that no one may remember I did an experiment that proved something, but the mechanism I discovered will be real forever. If I hadn't discovered it, someone else would have, no question. But at least I made some real contribution. That's my sense of it. So my advice would be to see how curious you are, and if you actually enjoy this process. I know I do.

This interview was edited for clarity.



Linear Programming: A Bluffer's Guide

Paul Michael Kielstra '22

Let's say that, for some reason, you have decided to get into the restaurant business. You have a certain budget to buy tables. Four-seat tables are cheaper than six-seat tables, and take up less space, but don't seat as many people. You need to work out how many of each sort of table to buy in order to maximize the number of seats you can fit in your restaurant while staying within your budget.

"The first thing to do is, as always in mathematics, to exactly define what we want."

This is a very basic example of a problem that has been known, in some form or another, since antiquity, but has only recently come to be referred to as linear programming. In a *linear programming* problem, you have a *cost function* $c(x_1, x_2, \ldots, x_n)$ which takes some variables x_1 through x_n, and you want to pick values for those variables that minimize the cost (or, equivalently, maximize the reward) subject to a series of *constraints*, each of which is of the form $\sum a_n x_n < b$. In our restaurant example, maybe four-seat tables cost \$100 each and take up $2m^2$ of floor space, while the six-seat tables cost \$200 each and take up $3m^2$. If we have a budget of \$1800 to fill $30m^2$, we'd get the following linear problem:

$$\begin{aligned} &\text{Maximize } 4x_1 + 6x_2 \\ &\text{s.t. } 100x_1 + 200x_2 \leq 1800 \\ &2x_1 + 3x_2 \leq 30 \end{aligned}$$

The function to maximize, $4x_1 + 6x_2$, is the total number of seats. The first constraint is the budget (the total price of the tables, $100x_1 + 200x_2$, must be at most 1800), the second is the floor space, and "s.t." just means "subject to".

If you haven't seen this sort of problem before, it isn't immediately obvious how to do the math on it. (The answer, by the way, is to buy six of each type of table, for a total of sixty seats.) To make matters worse, most linear programming problems today aren't done with just a few constraints like this. They're used to model things like transportation problems, in which companies with hundreds of warehouses and thousands of trucks try to move just enough goods between them all while minimizing the amount of fuel they need to buy. Just doing it by hand, even if we could work out how, wouldn't be enough.

The first thing to do is, as always in mathematics, to exactly define what we want. Linear programming problems are just that: linear. We'll never be asked to minimize x^2 or make sure the solution has $\cos x < ⅓$. This gives us our first insight: we don't need to consider every

such problem (commonly called a *program*) individually. Instead, we can use matrices to write them all in a more general way:

$$\begin{aligned} &\text{Maximize } c \cdot x \\ &\text{s.t. } Ax \leq b \end{aligned}$$

In this scenario, c, x, and b are vectors, and A is a matrix. Our restaurant program now looks like this:

Right now, it just looks like we're doing linear algebra

$$\begin{aligned} &\text{Maximize } \begin{pmatrix} 4 \\ 6 \end{pmatrix} \cdot \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \\ &\text{s.t. } \begin{pmatrix} 100 & 200 \\ 2 & 3 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \leq \begin{pmatrix} 1800 \\ 30 \end{pmatrix} \end{aligned}$$

for the sake of doing linear algebra. That's only partially true. We are, in fact, setting ourselves up for a logical leap that will give us a way to properly solve these programs. Note that, since, in any solution, $Ax \leq b$, there must be some vector $y > 0$ such that $Ax + y = b$. Moreover, in general, we would like y to be small, so that Ax, and thus x, and thus $c \cdot x$, is as large as possible. We call y the *slack*.

"We are, in fact, setting ourselves up for a logical leap that will give us a way to properly solve these programs "

This suggests trying to minimize the slack and seeing what kind of solution that gets us. Of course we can't just set $y = 0$: maybe there are no solutions to $Ax = b$. So, we need some more constraints, within which to minimize y. It turns out that the correct constraints give a very elegant linear program, called the *dual*:

$$\begin{aligned} &\text{Minimize } b \cdot y \\ &\text{s.t. } A^T y \geq c \end{aligned}$$

(If we have a dual problem, the original is called the *primal*. The vectors b and c have the same values in the primal and the dual; we just change their roles. A^T is the transpose of A, calculated by turning coumns into rows and vice versa.)

For the next bit, we'll need the idea of a *feasible solution*. This is some solution which doesn't necessarily minimize the cost or maximize the reward (it isn't *optimal*), but it is within the constraints. In the restaurant example, "don't buy any tables" is a feasible solution. It doesn't maximize the number of seats, but it does t within the budget and space available. In our matrix terminology, a feasible solution to the primal problem is just any x such that $Ax \leq$ b. A feasible solution to the dual is any y such that $A^T y \geq c$.

"It's a greedy algorithm – tries to get the maximum possible short-term reward without thinking ahead"

The Strong Duality Theorem, which is fairly awkward to prove, shows that, if you have feasible solutions x to the primal problem and y to the dual such that $Ax + y = b$ – that is, if you have feasible solutions to both problems where one represents the slack in the other { then both are optimal. In a very handwavey, intuitive way, this makes sense: the primal and dual programs approach the problem from opposite sides, one trying to increase the reward and the other trying to minimize the costs, so they "meet in the middle" at the optimal point.

This tells us everything we need to nally start solving linear programs. We can always find a feasible solution to the dual problem: just take y to be so enormously huge that $A^T y$ can't help but be greater than c. This lets us figure out the x that corresponds to our y; unless we're very lucky, it won't be feasible to the primal problem yet. Then we systematically decrease every component of y in turn, one after the other, staying within the constraints, and keep recalculating the related x, until we finally get feasible solutions to both problems. At this point, they're both optimal, and we're done!

If you want to read more about this process, a good reference, with proofs and exercises, is the appendix of *Combinatorial Optimization* (Cook, Cunningham, Pulleyblank, & Schrijver, 1998). This also includes a discussion of the *simplex algorithm*, the current best and most accurate algorithm for actually solving complicated linear programs in practice. It's a greedy algorithm – that is, an algorithm which always tries to get the maximum possible short-term reward without thinking ahead – which works by first calculating which component of y has the most effect on x and then decreasing that as much as possible. It always succeeds in the end, but sometimes it takes quite a long time to do so. There was a result published only a few months ago (Forsgren & Wang, 2019) which proved that you can speed it up, but didn't give any clue as to how.

As restaurant owners, then, we are satised, but as

mathematicians we can see many dierent ways forward. The field of linear programming is very strange in this way: its central problem is fundamentally solved, but there is still research going on around the world. This very brief article has barely scratched the surface of the complexity of the subject, and I encourage you to investigate further.

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What's Really Going on in the Amazon Rainforest?

Seo-Hyun Yoo '23

An Overview of the Amazon and its Benefits

The Amazon Rainforest is universally recognized for the beautiful landscapes and vital habitats that it provides some of the most diverse organisms in the world. The Amazon also produces approximately 6% of the world's atmospheric oxygen in a given year (Leman). Given its photosynthetic power, it's not surprising that the Amazon also acts as a major carbon sink and absorbs up to 2 billion tons of carbon dioxide every year (Kaiser).

"The Amazon also regulates climate by cycling water through the atmosphere"

Carbon dioxide is one of the main greenhouse gases contributing to climate change. Greenhouse gases are responsible for the greenhouse effect, which allows visible/UV short-wave radiation from the sun to pass through the atmosphere, then blocks longer infrared wavelengths of radiation from the heated earth from escaping. The greenhouse effect is the main cause of global warming, and by extension, climate change. The consequences of climate change vary across different regions of the world, but they generally include sea level rise, intensification of storms and droughts, ocean acidification, changes in water resource availability, loss of biodiversity, and degradation of human health.

The pastures and harvest land that have been replacing the Amazon have a significantly greater net carbon production due to their lower carbon sequestering abilities. The Amazon also regulates climate by cycling water through the atmosphere, houses unique resources for medicines and other products, and provides a home for nearly 500 indigenous communities (*Why is the Amazon Important?*).

Shifting Land Use in the Amazon Basin

The majority of the Amazon Rainforest lies within Brazil (3.5 million square kilometers). Over hundreds of years, land use in the Amazon Basin–land draining to the Amazon River and mostly covered by the Amazon Rainforest–has undergone a series of changes. These changes have necessitated the protection of its resources and indigenous peoples. 70 million hectares have some form of legal protection, but even this has not stopped illegal logging (*Land Use and Agriculture in the Amazon*).

The Amazon that we know today is a landscape manipulated by thousands of years of human use. Traditional shifting cultivation, or "slash-and-burn"–in which a small clearing is cut in the forest and slash

material is left to add nutrients to the soil–has been used by the indigenous peoples of the Amazon Basin to account for its high precipitation and low soil fertility. This land is used for a few years to grow annual crops, then perennial crops, before being left to grow back as part of the forest. Farmers return to these particular patches of land after decades, allowing for the land to revert back to forest in a sustainable manner (*Traditional Land Use and Shifting Cultivation*).

Land use in the Amazon has since evolved starting with the introduction of timber harvest and rubber extraction in the 1600s. Large scale forest conversion has significantly reduced forest coverage since the 1970s. The majority of the land has gone to the development of cattle pastures and urbanization, as well as Brazil's prominent soybean industry. This forest conversion generally involves deforestation through lumber harvest. Like in shifting cultivation, what remains is burned in order to clear the land during the drought period and prepare for the planting season. Unlike the fires of the traditional slash and burn method, these fires clear large swaths of land and threaten the vitality of the Amazon, especially since land cleared in this way is rarely returned to the forest (*Land Use and Agriculture in the Amazon*).

Fiery Politics in the Amazon

The vast majority of fires in the Amazon are set by humans, particularly farmers and loggers clearing land, and the recent fires are no different. At the same time as fire occurrences increased, farmers and ranchers of Northern Brazil planned a "Day of Fire" for August 10th, when they set fires to clear land for pastures and farms. The eye-catching movement was to communicate to the federal government that they wanted to work as political change took place in the post-recession Brazilian economy.

"Land use in the Amazon has since evolved starting with the introduction of timber harvest and rubber "

Jair Bolsonaro, the current president of Brazil, was sworn in on January 1st, 2019 after the 2018 presidential election. Since he has taken office, he has made a sequence of political decisions that have loosened the government's authority over environmental regulation in the Amazon Rainforest. This authority is projected through IBAMA, the administrative department of the Brazilian Ministry of the Environment. In April, Bolsonaro cut the IBAMA budget by 24 percent. Until August 2019, IBAMA had only issued a third of the fines it had in the year prior. After INPE, the Brazilian space agency, released data showing a 278% increase in deforestation compared to last year, Bolsonaro had the institute's director fired (Sullivan). The deprioritization of conservation efforts in the federal government have sparked further consequences.

"The causes of these fires is linked to not just the ecology or economics, but the politics of the country"

The Brazilian federal government's projection of political priorities through these moves has encouraged the uptick in deforestation and illegal clearing of land. Rhetoric by the president has challenged criticism of the country's environmental policies. Bolsonaro said in mid-July, "The Amazon is ours. [...] No country in the world has the moral right to talk about the Amazon" (Sullivan). This has encouraged illegal land use in the Amazon, especially in remote areas where the law is harder to enforce. The causes of these fires is linked to not just the ecology or economics, but the politics of the country.

What Now?

The value of the Amazon Rainforest should not be forgotten in the face of current political and economic challenges. The increase in fires serve as a reminder that environmental protection policy is vital to the preservation of our natural resources and the regulation of climate change-inducing factors. International backlash with statements calling the situation an "international crisis" by world leaders, activists, and celebrities has drawn attention to Brazil (@emmanuelmacron). At the G7 summit in August 2019, $20 million was pledged to the Amazon. However, Bolsonaro initially rejected the money due to a public argument with French President Emmanuel Macron (Kottasová et al.). This is a clear example of the consequences of climate change policy's transition into a political, partisan issue. Only time will tell how implementation of environmental protection measures will fare in the face of politics as it becomes more and more necessary around the globe.

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